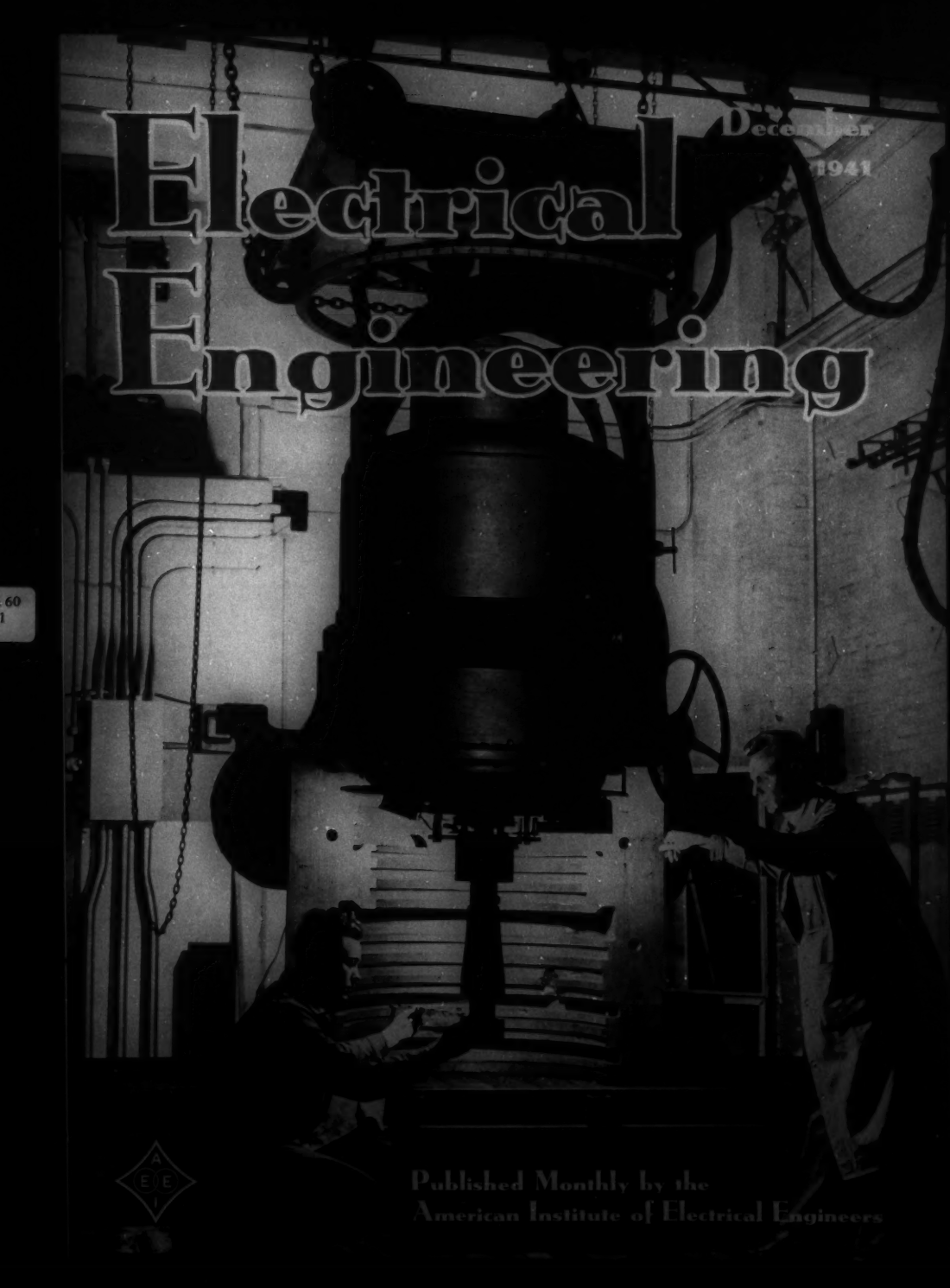
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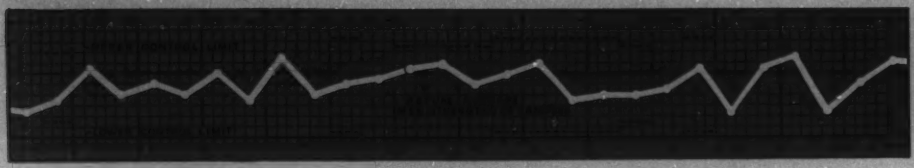
Engineering
December
1941
Published Monthly by the
American Institute of Electrical Engineers



Typical section of an O-B factory control chart, on which the average M & E strengths of the insulators tested each day are plotted. Falling of actual values within the control limits (determined by the number of insulators checked) indicates the desired uniformity is being attained.

Strength Isn't a Straight Line

But the Curves for Average Values and Deviations of O-B Suspensions Are Near the "Straight Line" Ideal

● Uniformity of M & E strength is supremely important for suspension insulators, mainly because the failure of a single unit could drop a line and interrupt service. Uniform insulators allow lines to be designed with a lower factor of safety than would be needed with erratic units. And insulators of uniform strength are superior in other vital properties.

To attain the highest possible degree of uniformity, O-B carefully inspects all raw materials and exercises extremely rigid control in every single manufacturing process. Going even further, O-B uses scientific, large-quantity sampling to secure reliable probability curves which permit accurate, continuous checking of factory control. How this system is applied may be seen in the accompanying typical charts, one for average values and the other for deviations of individual specimens from their average. Control limits are determined by the number of insulators in the samples, and the actual values are the results of *daily* tests. Should any average or deviation value fall outside these control limits, the cause of the observed condition is immediately found and corrective measures taken.

To benefit from this effective factory control system—assuring units with averages safely above rated values and having deviations small enough to guarantee dependable, satisfactory minimum strengths—be sure to specify O-B for your suspension insulators!

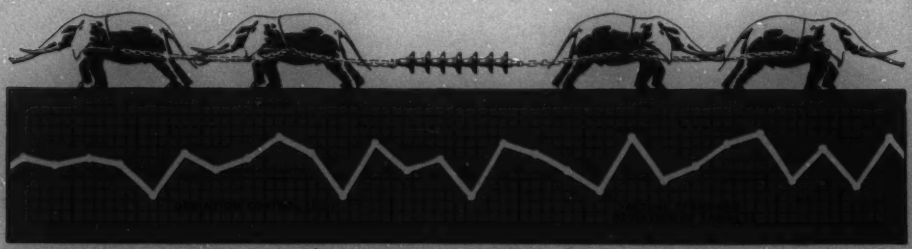
BUY THE BEST—BUY O-B!

Ohio Brass (B)

MANSFIELD, OHIO, U. S. A.

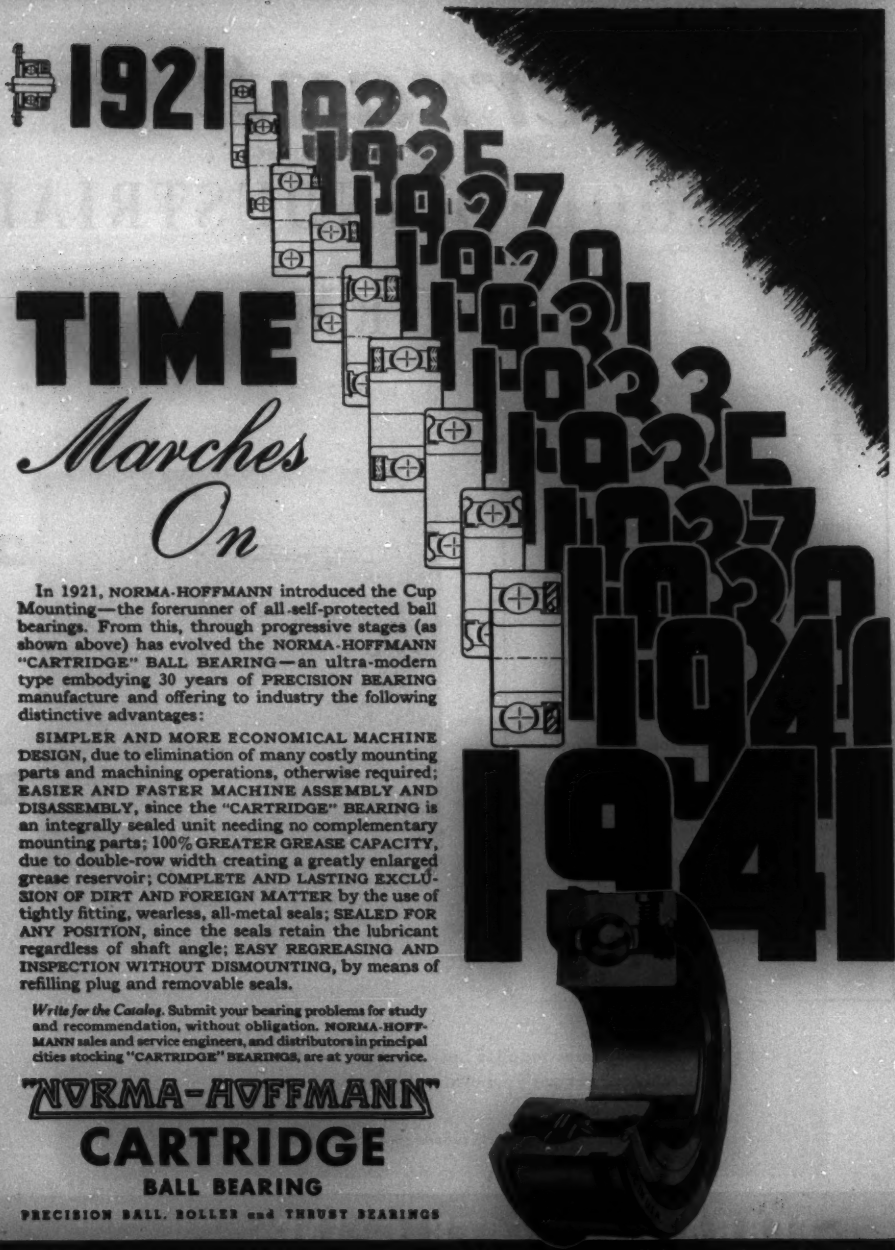
Canadian Ohio Brass Co., Ltd., Niagara Falls, Ont.

2208-H



Actual deviations of individual specimens from their average are plotted on this O-B control chart, providing another effective means for checking the uniformity of suspension insulators.

TIME *Marches On*



In 1921, NORMA-HOFFMANN introduced the Cup Mounting—the forerunner of all-self-protected ball bearings. From this, through progressive stages (as shown above) has evolved the NORMA-HOFFMANN "CARTRIDGE" BALL BEARING—an ultra-modern type embodying 30 years of PRECISION BEARING manufacture and offering to industry the following distinctive advantages:

SIMPLER AND MORE ECONOMICAL MACHINE DESIGN, due to elimination of many costly mounting parts and machining operations, otherwise required; EASIER AND FASTER MACHINE ASSEMBLY AND DISASSEMBLY, since the "CARTRIDGE" BEARING is an integrally sealed unit needing no complementary mounting parts; 100% GREATER GREASE CAPACITY, due to double-row width creating a greatly enlarged grease reservoir; COMPLETE AND LASTING EXCLUSION OF DIRT AND FOREIGN MATTER by the use of tightly fitting, wearless, all-metal seals; SEALED FOR ANY POSITION, since the seals retain the lubricant regardless of shaft angle; EASY REGREASING AND INSPECTION WITHOUT DISMOUNTING, by means of refilling plug and removable seals.

Write for the Catalog. Submit your bearing problems for study and recommendation, without obligation. NORMA-HOFFMANN sales and service engineers, and distributors in principal cities stocking "CARTRIDGE" BEARINGS, are at your service.

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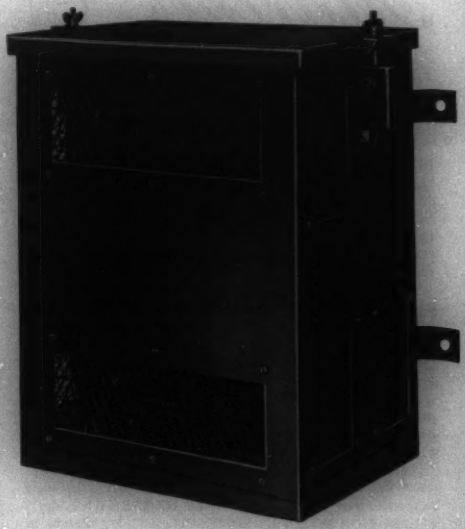

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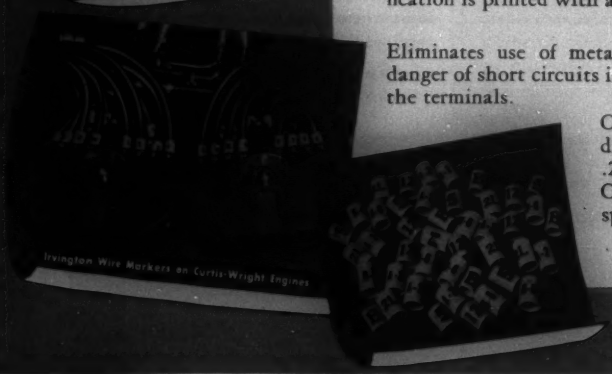

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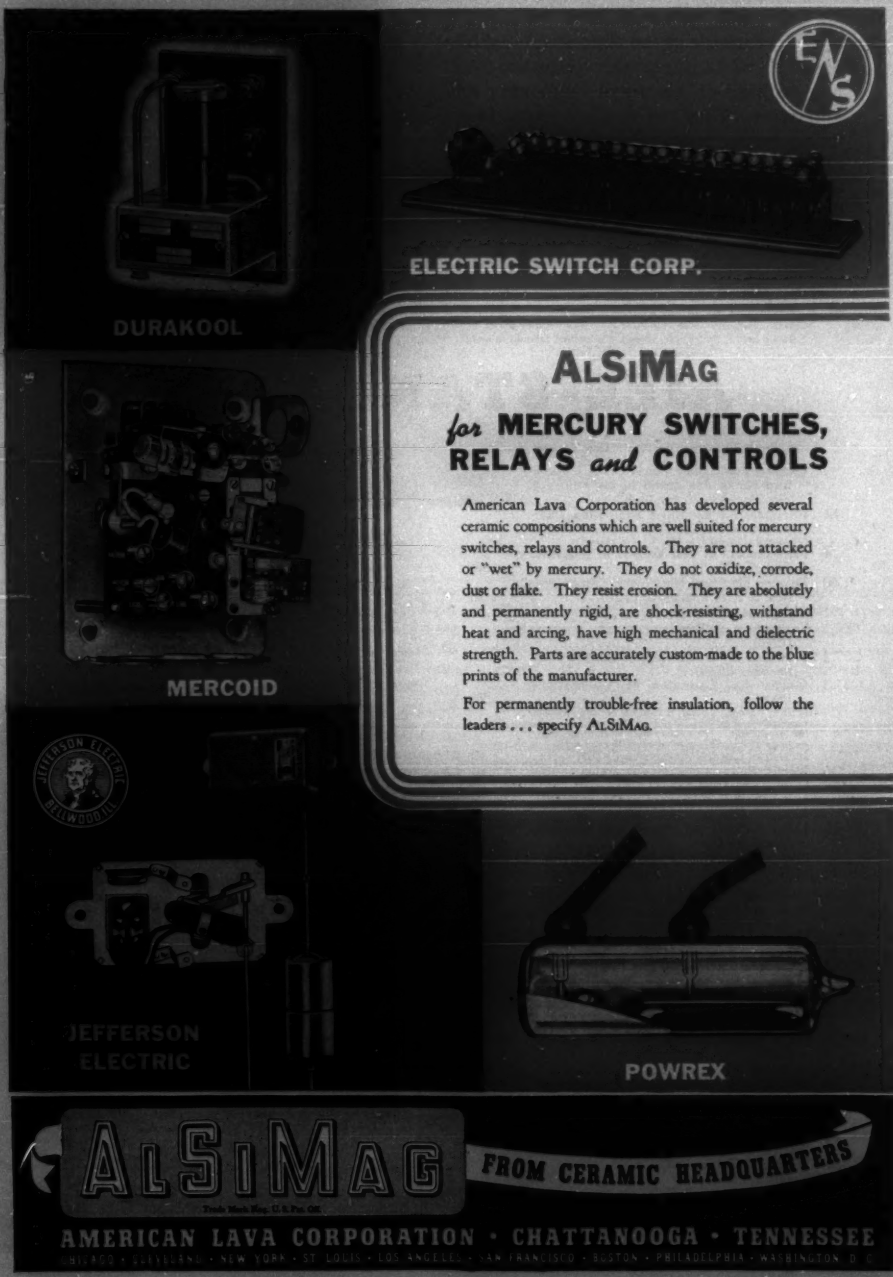

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21	Apparatus Bushings (3-41) (Including Test Code)	40	Electrical Recording Instruments. (6-33)
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WHAT WILL TEN OR TWENTY YEARS DO TO THE HIGH-VOLTAGE INSULATORS ON YOUR SYSTEM ?

How many lines on your system are still hanging on the same insulators installed twenty years ago? On lines or stations twenty years old, how many insulators have been replaced, and how many are replaced every year? In most companies high-voltage insulator replacement runs a sizeable annual bill—to say nothing of lost revenue and ill-will created by lines being temporarily out of service.

Maybe you don't expect high-voltage insulators to be permanent. If they hold up a few years and then start to need replacement, you think you're getting all you could hope for. Under the right circumstances a thin section of the best porcelain may puncture. As they contract and expand, it's only natural that nested shells should sometimes crack. The intense heat of a power arcover can't help but fracture off a thin spreading shell. And so on.

Ten years ago, Lapp introduced the Post insulator—a high-voltage unit with a promise that it would never need apologizing for. All of the things that caused failure in conventional pin-type insulators were eliminated. A sturdy post body, with multiple short petticoats, it practically never would give out under power arcover or mechanical attack. (When one or two petticoats did let go, flashover and leakage values would still be great enough to maintain unimpaired service.) It was of one piece, with hardware externally attached—no nested shells, no opportunity for cracking. It offered *uniform* leakage distance, complete and permanent freedom from radio interference, extra rigidity and impact strength.

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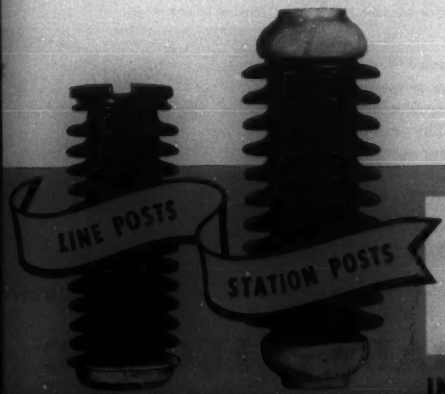
Insulation with Lapp Line Posts and Station Posts appears to be the closest thing to permanent insulation ever offered for high-voltage power transmission.



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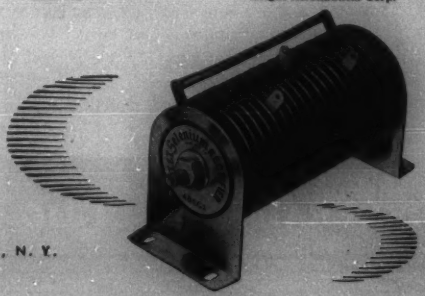

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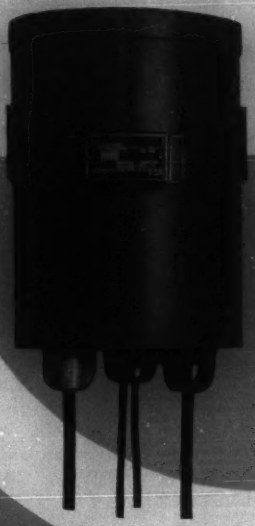

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For outdoor metering applications
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230, 460, and 575 volts—full-wave, 50 kv;
2300 volts—full-wave, 60 kv

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NOW, G. E. OFFERS...A complete line of outdoor current and potential transformers, 15 kv and below, which conform to ASA insulation standards

These new standards, which are met by this now complete line of transformers, provide a means whereby all apparatus on a line can be co-ordinated to have the same insulation strength. This facilitates the selection of adequate protective equipment.

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for December 1941—

The Cover: Million-volt industrial X-ray unit, will radiograph five-inch steel plates and castings in four minutes (see pages 571–3)

Photo courtesy General Electric Company

The Dual Rating of Electrical Apparatus	...P. L. Alger	... 569
Million-Volt Industrial X-Ray		... 571
The Manufacture of Incandescent Mazda Lamps	...James D. Hall	... 574
Progress in the Art of Metering Electric Energy—IV	...AIEE Subcommittee	... 581
Ten Years of Progress in Relaying	...AIEE Committee	... 590
Miscellaneous Short Items: Ultraviolet on a Dairy Farm, 580——20,000-Kva Synchronous Condenser, 592		
Institute Activities		... 593
Of Current Interest		... 606

Transactions Section *(Follows EE page 618, a preprint of pages 1003–50 of the 1941 volume)*

Field Testing of Generator Insulation	...EEI Subject Committee	...1003
Improving Electric Service by High-Speed Switching	...J. T. Logan, John H. Miles	...1012
High-Pressure Gas as a Dielectric	...Gordon C. Nonken	...1017
An Automatically Reclosing Breaker	...H. L. Rawlins, J. M. Wallace	...1021
Short Circuits in Synchronous-Machine Armatures	...R. A. Galbraith	...1024
Transient Overspeeding of Induction Motors	...Raymond W. Ager	...1030
A Cathode-Ray Method of Wave Analysis	...Vincent O. Johnson	...1032
Calculating Single-Phase-Motor Performance	...Wayne J. Morrill	...1037
A Novel Reclosing Relay	...P. O. Bobo	...1041
Inductance of Rectangular Tubular Conductors	...Thomas James Higgins	...1046

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High Lights • •

Generator-Insulation Field Tests. The need for a practical and reliable nondestructive test that will indicate the condition of generator insulation has been the subject of study by a special subject committee of the Edison Electric Institute's electrical equipment committee since 1935; investigation has been directed toward characteristics of insulation for such tests as insulation resistance, power factor, high-voltage alternating current, high-voltage direct current, and ionization as caused by high-voltage application (*Transactions pages 1003–11*).

Metering Development. The series of four articles on the development of the metering art, sponsored by the Institute's committee on instruments and measurements, concludes with a report on developments in calibration, installation, and maintenance of meters (*pages 581–6*). An appendix lists sources of information covering the entire series (*pages 587–9*). The whole report is being issued in pamphlet form (*page 597*).

Automatically Reclosing Breaker. Designed especially for co-ordination on extended distribution systems to eliminate service trips on temporary faults and restrict outages to the immediate neighborhood of a permanent fault, a small automatically reclosing oil circuit breaker has been developed with a pronounced inverse time on tripping; completely self-protecting, it requires minimum maintenance (*Transactions pages 1021–4*).

Relaying Progress. A decade's progress in relaying has been reviewed in a report prepared under the auspices of the AIEE committee on protective devices (*pages 590–2*). This is the second of three reports on developments in the protection of electric power-system circuits and equipment; the first, on circuit interrupters, appeared in November, and the third is scheduled for an early issue.

ECPD Annual Meeting. Rising consciousness of the need for active participation in the affairs of the Engineers' Council for Professional Development by its constituent organizations was indicated at Council's recent ninth annual meeting (*pages 606–08, 610*). The list of curricula accredited by ECPD to date also appears in this issue (*pages 608–09*).

Engineers Defense Board. A central agency prepared to assist the various branches of government with engineering experience has been set up by the formation of the Engineers Defense Board in which six national engineering societies are co-operating (*page 610*). Other news relating to national defense also appears in the section "Of Current Interest".

Wave Analysis. Complex periodic functions, transformed into corresponding voltage waves, may be analyzed with the aid of a cathode-ray oscillograph. The complex wave is represented upon the fluorescent screen of the cathode-ray tube by a vertical displacement, at the same time that a sinusoidal horizontal oscillation exists (*Transactions pages 1032–6*).

Million-Volt X-Ray Unit. Only a few years ago an 800-volt X-ray equipment required a special multistory housing, utilized a tube about a foot in diameter and 14 feet long; today's 1,000-kv unit occupies a 30- by $3\frac{1}{2}$-inch envelope, is housed as a self-contained unit in a tank 3 feet in diameter and less than 5 feet high (*pages 571–3*).

Dual Rating. Proposals for the dual rating of electrical apparatus, one governed by strength and the other by endurance limits, are outlined in a report recently issued by the AIEE standards committee. The committee hopes that the report will stimulate discussion that will lead ultimately to an improved system of rating (*pages 569–71*).

Dielectric Strength of Gas. Tests of impulse and 60-cycle breakdown strength have been made of nitrogen and Freon at gauge pressures up to 200 and 70 pounds per square inch, respectively, and dielectric strength values compared with the breakdown of transformer oil under similar conditions (*Transactions pages 1017–20*).

Calculating Motor Performance. A method of predetermining the performance of single-phase induction motors based on the development of charts to determine apparent impedances has been proposed; its practical value has been demonstrated by use in an industrial design department (*Transactions pages 1037–41*).

New Reclosing Relay. A reclosing relay has been designed and built specifically to meet the additional reclosing requirements created by complete automatization of high-voltage oil circuit breakers in transmission networks and on lines containing automatic sectionalizing air-break switches (*Transactions pages 1041–5*).

Transient Overspeeding. The transient swing above synchronous speed observed when a standard squirrel-cage induction motor is started without load has been explained by reference to the frequency modulation of the power supply caused by the rapid variation of the power taken from the line (*Transactions pages 1030–2*).

Inductance of Rectangular Conductors. Formulas have been derived by means of which can be calculated the inductance of single-phase circuits and certain polyphase circuits composed of solid or tubular rectangular conductors; a numerical example illustrates application of the single-phase formulas (*Transactions pages 1046–9*).

Improving Electric Service. Practices used by one power company to improve continuity and quality of service included high-speed circuit reclosure and methods of limiting voltage disturbances, or their effects on motor speeds, to values tolerable in the manufacturing processes of a particular industry (*Transactions pages 1012–16*).

Short Circuits in Armature Coils. An approximate solution for the current in a short-circuited coil or group of coils in the armature of a synchronous machine operating under load is expressed as the sum of a series of harmonics the terms of which are in geometric ratio (*Transactions pages 1024–9*).

Mazda Lamps. The production of incandescent Mazda lamps, from the processing of tungsten ore to the final assembly of parts, is surveyed and illustrated as it is carried on by a large manufacturing company (*pages 574–80*).

Coming Soon: Among special articles and technical papers currently in preparation for early publication are: an article on power-system development on a national scale by T. R. Tate (M'35), Federal Power Commission; an article on Heaviside's operational calculus by J. B. Russell (A'34); an article on protective lighting for American industry by Davis H. Tuck; an article on the cyclotron by W. M. Brobeck; a paper on the acceleration oscillogram method of motor torque measurement by C. R. Atkinson (A'31) and E. G. Downie (A'35); a paper describing field tests on high-capacity station circuit breakers by H. D. Braley (A'18); a paper on the frequency-modulated carrier telegraph system by F. B. Bramhall (M'39) and J. E. Boughtwood; a paper describing the performance of ground-relayed distribution circuits during faults to ground by C. L. Gilkeson (M'34), P. A. Jeanne (M'30), and J. C. Davenport; a paper describing a d-c telemeter or d-c Selsyn for aircraft by R. G. Jewell (A'30) and H. T. Faus (M'34); a paper on the relative values of different types of overcurrent protection for distribution circuits by G. F. Lincks (A'37); a paper on field tests and performance of a high-speed 138-kv air-blast circuit breaker by Philip Sporn (F'30) and H. E. Strang (M'39); a paper on temperature and electric stress in impregnated paper insulation by J. B. Whitehead (F'12) and W. H. MacWilliams (Enrolled Student); a progress report of d-c testing of generators in the field by E. R. Davis (A'41) and M. F. Leftwich (A'30); a paper on a method of calculating performance of current transformers based on admittance vector locus by A. C. Schwager (M'31).

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The Dual Rating of Electrical Apparatus

P. L. ALGER
FELLOW AIEE

AIEE Standards Pamphlet No. 1A entitled "General Principles for Rating of Electrical Apparatus for Short Time, Intermittent, or Varying Duty," recently was issued in report form for study and comment. In this article, the chairman of the committee that prepared the report discusses its significance, for the purpose of stimulating discussion of this important topic. Contributions to the Letters columns are invited.

EVERY material or device, from a rubber band to a locomotive, has two independent physical limits, one of strength and one of endurance. The rubber band may support a large weight without rupture, but heat aging or oxygen exposure ultimately will reduce its strength to zero. So also, an induction motor operating at constant voltage has a definite torque limit at which breakdown occurs, but a much lower continuous torque-carrying ability, determined by heating and insulation aging effects.

To select a locomotive for a desired train-speed characteristic on a mountain railroad, or an electric motor for an elevator, or even a type of steel for the buckets of a steam turbine, both the strength and the endurance limits must be recognized and allowed for. When a system is built up of many different apparatus types, therefore, both strength and endurance limits must be properly matched. We cannot attain the perfection of the deacon who designed the "wonderful one-horse shay," but we can very profitably follow the principles he laid down:

"Fur," said the Deacon, "It's mighty plain
That the weakes' place mus' stan' the strain;
'N' the way to fix it, uz I maintain,
Is only jest
To make that place uz strong uz the rest."

For convenience in matching assorted materials or apparatus types, it is very desirable that the name-plate ratings indicate these two limits of strength and endurance separately. That is, a dual output rating is required for any material or apparatus to be used in short-time, intermittent, or varying duty. Examples of such dual ratings in common use are the proportional and fatigue strength limits of metals, the one hour and continuous ratings of railway motors, and the impulse and 60-cycle dielectric strength of insulation.

This problem of suitably describing apparatus for varying-duty service has been under study by an AIEE committee for the past two years. It is of particular importance to the electrical industry because electric motors and controls are now so widely used in association with every variety of mechanical equipment to perform the varied tasks of industry. Electrical engineers have found laymen generally to be singularly impervious to ideas about temperature rise and commutation limits of electric motors; therefore, it is natural that they have sought a more generally acceptable way of defining the output limitations.

The first results of this study have recently appeared in the form of a report, AIEE No. 1A, entitled "General Principles for Rating of Electrical Apparatus for Short-Time, Intermittent, or Varying Duty." This report describes four distinct methods of rating such apparatus that are or have been frequently used, and proposes a new, or modified, "service factor rating" method for general adoption. This method is equally suitable for rating mechanical apparatus and materials, so that its use should facilitate the co-ordination of all the different elements in electromechanical systems of every sort.

The diagrams will assist in understanding the problem and its proposed solution. In Figure 1 is shown the output–time characteristic of an electric motor or other device. The maximum momentary load (P_m) that can be carried (say for one minute) is governed by the strength limit, fixed by breakdown torque, commutation, voltage regulation, or the proportional limit of the mechanical structure; and the endurance limit (P) is fixed by the temperature, chemical stability, and deterioration rates of the materials employed.

For any given type of apparatus, P_m and P may be independently varied over wide limits. For example, increasing the reactance of an electric motor or cable will reduce only its momentary load-carrying ability (for a given voltage), while heat insulating it will reduce only its continuous load-carrying ability (for a given insulation life). The curve equally well applies to a gas engine, a gear, or a steam turbine.

Obviously, the sustained load on the apparatus must be considerably less than P_m, and there must be a reasonable safety margin in addition to provide for unknown conditions of service. It is desirable, therefore, to choose a name-plate rating, P_n, representative of the load that is actually to be carried for repeated or sustained time intervals. Just how P_n is determined will depend on the type of apparatus and the service. It may represent a one-hour rating; or the average of a varying load over any agreed short time interval; or simply an arbitrary fraction of the required P_m value.

However, it is desirable to preserve an approximately fixed ratio of P_n to P_m for any given type of apparatus or system. For example, in the case of an induction motor, the stalled current being closely proportional to the breakdown torque P_m, a fixed ratio of P_n to P_m will make

Essential substance of an address presented at the AIEE South West District meeting, St. Louis, Mo., October 8–10, 1941.

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the P_n value alone a reliable indicator of all power-supply, fusing, and wiring requirements. A usual ratio of P_n to P_m for induction motors is 0.45 to 0.55, which assures ample torque margin for occasional operating peaks in excess of normal, and which corresponds to a stalled current of about five to six times the full-load value. As another example, in the case of arc-welding generators or transformers, the name-plate rating, P_n, may represent the actually expected welding current at maximum setting. This current is required only intermittently, over periods of a few minutes, as frequent idle periods are necessary for adjusting the work and replacing electrodes. The rms equivalent current over an extended period is rarely in excess of 80 per cent of the actual welding current, and so it is customary to use apparatus with a permissible continuous current materially less than the P_n value.

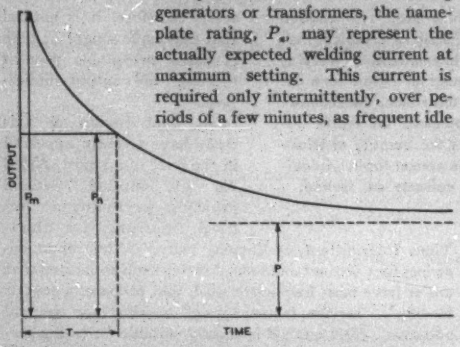


Figure 1. Output-time curve of an electrical device

P_m = Maximum momentary output, fixed by other than thermal limitations
P = Continuous output, or rating for continuous operation under known service conditions
P_n = Name-plate rating, or sustained load that may be carried in intermittent, short-time, or other specified duty. In the case of general purpose apparatus, P_n may be slightly less than P, to provide a margin where service conditions are unknown
T = Time associated with short-time rating
$S = P/P_n$ = Service factor

On this basis, therefore, the name-plate rating of any apparatus for short-time, intermittent, or varying duty ought to define the values of both P_n and P. The remaining question is whether to give both P_n and P directly, or the ratio P_n to P (greater than unity), or the ratio P to P_n (less than unity).

If both P_n and P are given directly, as in the case of the one-hour and continuous horsepower ratings of a locomotive, for example, it becomes necessary always to say which kind of horsepower is intended. It is as confusing as if coal weights were measured in both long and short tons, with the ratio of a long to a short ton varying under different conditions.

Comparison of an electric with a Diesel-electric locomotive, both having the same continuous rating of 4,600 horsepower affords an excellent illustration of this difficulty. The Diesel-electric, having no external source from which to draw power, can deliver 4,600 horsepower continuously, but cannot exceed this output even momentarily. The electric locomotive, being able to draw far more than continuous rated current from the trolley wire, can deliver far more than its continuous rated horsepower for short periods, within the thermal limits of the apparatus, as shown by Figure 2. In the case illustrated, the electric locomotive has a peak capacity of 8,800 horsepower and can deliver 7,000 horsepower for a considerable period, so enabling speed to be maintained on upgrades. It is not fair, therefore, to call them both 4,600-horsepower locomotives, nor is one a 4,600- and the other an 8,800-horsepower unit. They must be compared on a dual-rating basis.

If the continuous rating, P, is taken as the basic value, and the greater-than-unity ratio, P_n/P, is used to indicate the permissible operating load, another sort of confusion arises. Consider the case of a normal open-ventilated motor, with a continuous rating of 100 horsepower, for example. If the ventilation is shut off completely, the motor may become dangerously hot even at no load, and its continuous rating will be reduced to a small fraction of 100 horsepower. Yet, physically, and so far as stalled current, momentary power demand, breakdown torque, and short-time load-carrying ability are concerned, the motor is still a 100 horsepower unit. Conversely, by providing forced ventilation, the permissible continuous rating may be appreciably increased, but the torque limitations and power-demand characteristics will be unchanged. Hence, the continuous rating is greatly affected by ventilation, but is not a good index of physical size, cost, torque ability, or power-supply requirements.

The situation is as if a hoist were designed to lift a ten-ton weight once every ten minutes. Shall this be called a one-ton hoist, because it does the same average amount of work as another hoist lifting a one-ton weight through the same distance once each minute? Certainly the ten-ton lifting capacity requires greater size, stronger foundations, and has a greater cost, than the one-ton lifting capacity. It is, therefore, unreasonable to give them the same name-plate rating.

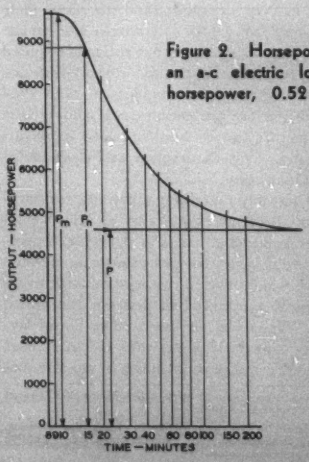


Figure 2. Horsepower-time curve of an a-c electric locomotive (8,800 horsepower, 0.52 service factor)

P_m = 9,600 - horsepower maximum momentary output fixed by mechanical and commutation limitations
P_n = 8,800 - horsepower nominal accelerating rating developed for a fraction of a minute during every acceleration
P = 4,600 - horsepower continuous rating
$S = P/P_n$ = 0.52 service factor

There remains the plan of taking the permissible operating load, P_n, as the basic, or name-plate rating, and designating the permissible continuous load by a factor less than unity. As already indicated, with a reasonably uniform ratio of peak output capacity, P_m, to the operating load, P_n, the latter figure gives a fair measure of the physical size, power demand, and basic cost of the apparatus. To give the two hoists of the preceding paragraph ratings of ten tons, 10 per cent time on, and one ton, 100 per cent time on, respectively, is altogether natural and understandable to the layman. This, therefore, is the recommendation made in the AIEE Standards Report No. 1A.

For convenience, and exact expression, the name "service factor" has been given to this ratio, P/P_n, of the permissible continuous load to the normal operating load. The term "service factor" bears a close analogy to the familiar term "load factor," which expresses the ratio of the average to the peak power demand of any system. In each case, a low service factor, or a low load factor, implies a large physical plant and high stand-by charges, compared with a system having a high service factor or load factor and the same annual power consumption. Also, a low service factor, or a low load factor, implies a high ratio of peak-load-carrying ability to continuous capacity.

The recommendations of this AIEE committee report may be summarized in a few brief statements; for all short-time, intermittent, or varying-duty apparatus (referring to Figure 1):

1. The name-plate rating, P_n, should indicate the permissible frequently repeated or sustained load.

2. The momentary peak-load capacity, P_m, should bear an approximately constant relation to P_n, for any given type of apparatus, in associated system elements.

3. The permissible continuous load that may be carried for an indefinitely long period without injury, P, should be indicated by a service factor, S, less than unity, applied to the name-plate rating: $P = SP_n$.

To put these suggestions to practical use, and adopt or modify them for industry standards of rating, is a task for the future that will take considerable time. The report will amply serve its purposes, however, if it excites discussion and ultimate concerted action to improve our American methods of apparatus rating.

In closing this discussion, it should be pointed out that a major reason for bringing this matter to the fore at the present time is the more exact knowledge now available of life temperature effects, or aging, of materials. Chemical knowledge, and many tests, indicate that organic insulating materials deteriorate more rapidly at elevated temperatures, in such a way that the life is halved for each 8- to 12-degree-centigrade increase in temperature. On the basis of this law, and knowing the load–temperature characteristics of the apparatus, it is possible to sketch in the entire load–life curve of Figure 1, if the end points, P_m and P, are given. Hence, it is now possible to fit apparatus for intermittent-duty service much more exactly to the requirements than heretofore.

With the increased variety of industry requirements, it is becoming necessary to secure closer thermal co-ordination of all the elements of an electrical system than ever before. The time–current curves for operating, stalled, and short-circuit conditions must be studied for motors, relays, wiring, and power-supply devices, and made consistent with each other. Better knowledge, coupled with more exacting demands, therefore, give a double indication of the need for more precise methods of apparatus rating, as outlined in the AIEE Standards Report No. 1A.

Million-Volt Industrial X-Ray Unit

THREE DEVELOPMENTS of co-ordinated research stand out as major factors in the General Electric Company's noteworthy achievement of a 1,000-kv portable industrial X-ray equipment: (*a*) dichlordifluormethane ("Freon") instead of air or oil as an electrical insulating medium; (*b*) a compact air-core resonance transformer; (*c*) a multisection X-ray tube small enough to be accommodated within the core space of the transformer. The result of the development and combination of these and other elements is the 1,500-pound self-contained million-volt equipment shown on the front cover and these pages.

An extended investigation of the electrical insulating properties of many gases and chemical vapors disclosed that some of them not only were far superior to air at equivalent pressures, but also provided better insulation than oil and were much lighter in weight. One of these special gases which is readily available and which has good physical and chemical properties is dichlordifluormethane (Freon). It has 2.5 times the insulating strength of air at equivalent pressures.

Freon 12, which has one carbon, two chlorine, and two fluorine atoms per molecule has, at 50 pounds per square inch pressure, a dielectric strength three times as great as the purest transformer oil. In a very high-voltage unit, 100 pounds of this gas will give insulation equivalent to that provided by 12,000 pounds of oil. Gaseous admixtures cannot contaminate Freon the way water or other foreign matter contaminates oil. The breakdown values of Freon are consistent, whereas oil is erratic.

The heat-transfer problem inherent in gas insulation was solved in this X-ray equipment by means of a small built-in cooler which utilizes a 1/15-horsepower fan to circulate the Freon gas over finned water-cooled copper tubing and through the transformer. At low ambient temperatures, such as may occur in industrial plants in winter, the Freon must be kept at summer temperature by electric heaters to keep it from condensing on the tank walls.

In the ordinary high-voltage transformer the charging current serves no directly useful purpose, but is a necessary evil, since it serves to reverse the potential of the high-

A very few years ago an 800-kv X-ray equipment required a special multistory housing (3) and utilized a multisection X-ray tube about a foot in diameter and 14 feet long, as compared with the 30- by $3^1/_8$-inch envelope (1) required for this 1,000-kv tube. Today's million-volt industrial equipment (4) weighs about 1,500 pounds, is housed as a self-contained unit in a tank 3 feet in diameter and less than 5 feet wide, can be swung into any operating position at the touch of a hand. To facilitate a comparison, illustration 3 and its small insert are shown to approximately the same scale in terms of the man shown in (3). In the view of the partially disassembled 1,000-kv unit (2), the resonance transformer may be noted, with its shielding cap and with the tube at its center

Especially under the pressure of defense production, radiography increasingly has become an essential step in the manufacture of vital equipment that must be dependable under severe operating requirements. Time is an essential element in this operation, and the greater the power behind the X rays, the less the time required. Five-inch steel plates and castings that can be radiographed in four minutes with the 1,000-kv equipment require four hours with 200-kv equipment

voltage terminal of the equipment, which has a considerable capacity to ground. In the resonance transformer this charging current is made to flow through a large inductance coil without iron core and thereby put to good use in producing exactly the high voltage wanted. In other words, the inductance of the coil and the capacity of the high-voltage terminal have been chosen to resonate at the frequency (180 cycles per second) of the power supplied to the transformer.

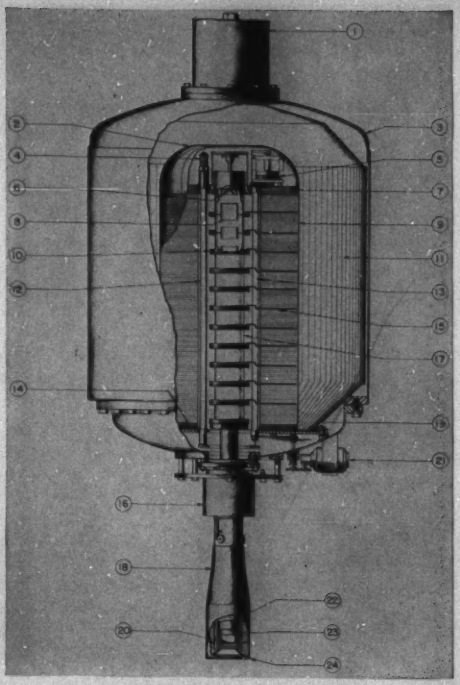
Some 238 miles of insulated wire are accounted for in the transformer. The high-voltage coil is 30 inches high, with 18-inch outside diameter and 8-inch inside or core diameter, and consists of thin coil elements stacked on top of each other with the primary "pancake" at the bottom. The high-voltage terminal on top of the transformer is a rounded brass spinning, $6\frac{1}{2}$ inches high and 18 inches in diameter. A uniform voltage gradient over the 30-inch height of the coil stack makes possible the use of glass rods as mechanical tie-rods to hold the stack together, thereby allowing operation in any position.

The 12-section sealed-off X-ray tube especially designed to go with this resonance transformer has cylindrical accelerating electrodes in each of the intermediate sections between the cathode and the copper-backed tungsten target. These intermediate electrodes are joined to the glass envelope of the X-ray tube with Fernico ring seals. Fernico is a special alloy which has an expansion coefficient comparable with one of the borosilicate glasses, thus permitting heavy metal sections to be fused directly to the glass. This feature allows the tube to be made much smaller than otherwise might be possible (the insulating tube envelope is only 30 inches long, $3\frac{1}{2}$ inches in diameter) and also permits the tube to be rigorously exhausted before it is sealed off the pump. The inside glass walls of the tube envelope are sandblasted to reduce the hazards of field emission. The tube is supported entirely by a metal flange joined to the grounded extension chamber. This extension chamber houses the target-end of the X-ray tube and thus permits the target to be placed inside of boiler drums and in other such relatively inaccessible positions.

The tube is mounted in the space at the center of the high-voltage transformer, where it adds nothing to the size of the housing tank required for the equipment. Thus mounted, the tube is located in a uniform electric field and a weak magnetic field, the axes of which parallel the tube axis. Early experiments established that the tube could be shifted sideways in the transformer without effect on the operation or on the size of the focal spot. Small toroidal shields of a conducting Textolite are used around all Fernico seals to reduce the field strength at the Fernico edges, to aid the focusing action of the intermediate electrodes and to provide a contact point for the tap strips which connect the intermediate electrodes to the inside of the transformer coil. The tap connections fix the potential of the electrodes and allow d-c charges to flow from the tube electrodes.

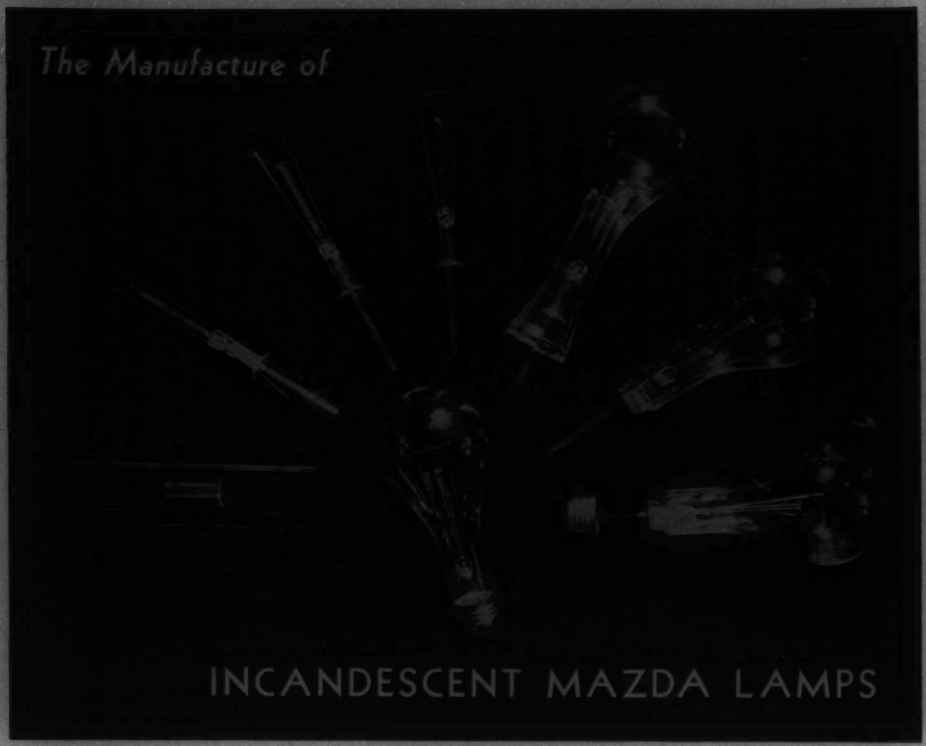
A focus coil is provided outside the tank, around the cooling-water jacket of the extension chamber, to focus the electron beam onto the tungsten target. The focal-spot diameters may be chosen to correspond to the tube current, which can be adjusted from microamperes up to three milliamperes at a million volts. Power for the cathode filament is derived from end-turns on the high-voltage winding and is controlled by means of a variable reactor operated through a glass-rod control shaft by an external filament-control motor.

Approximately 4 kw of power is required to operate the equipment at 1,000 kv and 3 milliamperes. This is supplied by a small synchronous motor-generator set which serves also to eliminate the effects of fluctuation in line voltage and to maintain accurately the frequency of 180 cycles per second for which the equipment is designed.



Million-volt portable X-ray unit

1. Cooler
2. Slotted brass shield
3. Steel tank
4. Spring for tie-rod
5. Variable reactor
6. Cathode assembly
7. End-turn filament coil
8. First intermediate electrode
9. Secondary coils
10. Shields around the X-ray tube
11. Laminated shield
12. Glass tie-rod
13. Insulating shaft for filament-control
14. Primary winding
15. Tap lead
16. Focusing coil
17. Glass envelope
18. Lead shield, adjustable
19. Laminated steel bottom
20. Tungsten target
21. Filament-control motor
22. Water jacket
23. Extension chamber
24. Lead diaphragm



JAMES D. HALL

From tungsten ore to assembled lamp, the production of a Mazda lamp at the Westinghouse lamp factory at Bloomfield, N. J., is here surveyed

REMARKABLE AND ROMANTIC as was the transition over the centuries from the caveman's torch to the first incandescent lamp, the advance from that carbon-filament vacuum lamp to the present gas-filled Mazda lamp is even more so. In a relatively short time, the industry has grown from one small workshop, producing a few carbon lamps made entirely by hand, to spacious factories, using raw materials drawn from every corner of the earth and employing thousands of people and amazing automatic machinery to produce annually millions of lamps of many kinds and for many and varied purposes. This rapid advance in the art was accomplished only by the tireless effort of hundreds of scientists, engineers, chemists, and metallurgists, each an expert in his own field and each contributing his bit towards making the Mazda lamp what it is today.

JAMES D. HALL: commercial engineer, Westinghouse Lamp Division, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.

TUNGSTEN WIRE

Of the many exacting processes used in the various stages of lamp manufacture, none necessitates greater knowledge, accuracy, and care than are required in the making of the tungsten-wire filament, the light-producing element. The high melting point of tungsten (3,392 degrees centigrade) prevents its being melted in crucibles because no crucible material having a higher melting point is available. Its peculiar crystalline characteristics are such that it cannot be drawn in the manner common to the drawing of many other metals, such as iron, copper, nickel; hence there have developed the rather devious and interesting methods used to transform the tungsten

ore into a wire having a tensile strength greater than that of the highest grade of steel.

The tungsten ore, in the form of a coarse brown powder, is first chemically analyzed (figure 1) for detection of 14 different impurities. If an excess of any one of the impurities is found, the lot is rejected. If the chemical requirements are satisfactory, the ore is ground to a talc-like powder in preparation for the chemical processes to follow. Of these highly technical processes it is sufficient to say that from the raw ore to the pure tungsten powder, the tungsten varies in form from a black powder, to a black solution, to a white crystalline powder, then to a yellow sulphur-like mass (tungstic oxide). These processes involve the use of hot and cold water, caustic soda, calcium chloride, hydrochloric acid, ammonia, and caustic potash. Each process is safeguarded by every available type of automatic equipment.

Following these chemical treatments, the yellow tungstic oxide is filtered and then dried in steam-heated kettles and ovens to remove the water (figure 2). The resultant powder is then ground and sifted and is ready for the addition of certain chemicals which produce the desired crystal structure in the finished lamp filament. The nature of this structure varies with different types of lamps, according to the service in which they will be used.

Next the powder in metal containers or "boats" is placed in airtight steel pipes enclosed in gas-heated furnaces. At regular intervals, the "boats" are moved forward through the pipe to meet an increasingly greater temperature as they reach the end of the furnace. During the heating, all water and oxygen are driven off and removed from the pipes by means of a continuous flow of pure hydrogen gas over the powder.

Next, each batch of powder is thoroughly mixed to insure uniformity. After being sieved through a fine silk screen, the powder is placed in a mold and subjected to a hydraulic pressure of some 20 tons per square inch, producing a bar 3/8-inch square by 24 inches long (figure 3). This bar is very brittle, like a cake of compressed talc, and must be handled with great care until it is baked in a hydrogen atmosphere in a gas furnace. This baking, as in a brick kiln, imparts sufficient strength to the bar to allow its handling in the subsequent processes. Following this, the bars are placed in cylindrical airtight metal containers known as "treating bottles." After each bottle is closed, it is filled with pure hydrogen gas and a current of from 1,500 to 2,500 amperes is passed through the bar for varying periods. The passage of the current through the bar fuses the tungsten particles, shrinking the bar, increasing its strength, and causing it to assume a metallic appearance.

From the time the powder is mixed until inspection of the metallic bar is completed, the operations are conducted in a room in which the temperature and the humidity are kept constant by automatic control. Experience has shown that normal fluctuations in weather conditions produce variations in the quality of the tungsten filament.

The next step in the manufacture of the filament wire consists of swaging or hammering the tungsten bar (figure 4) after it has been heated in an electric furnace in an atmosphere of hydrogen. The swaging is continued with the bar changed into a rod which gradually diminishes in diameter and increases in length. When the tungsten has reached the required diameter, it has attained sufficient tensile strength to make it workable in the next process. This increased strength results from elongation and overlapping of the crystals, a transformation that may be compared roughly to that occurring when a mass of hempen fibers, which has little strength, is made into a rope by weaving and intertwining the individual strands.

Further reduction in the diameter of the wire is accomplished by means of a die-drawing process, wherein the wire is lubricated by graphitic carbon and then heated to a carefully regulated temperature and drawn through dies of composition metal. This drawing is continued until the wire is about ten mils in diameter and then as the wire approaches its final size, the ultimate in accuracy as to roundness and diameter is achieved by the use of diamond dies, in the same type of process (figure 5).

The diameter of finished wire is determined by weighing a given length and computing the diameter from the weight and length. For the weighing of filament wire, delicate torsion balances, accurate to 2/1,000,000,000 of a pound, are used. The roundness of the holes in the diamond dies is checked to 1/100,000 inch by means of high-powered optometers. These instruments, like a microscope, enlarge the hole 300 times.

The smallest filament wire now produced is that used for the 3-watt 115-volt lamps. It has a diameter of approximately 3/10 mil or about 1/5 the diameter of a human hair. Specifications require that this diameter be held in commercial production to within plus or minus one per cent, or about 3/1,000,000 inch.

Approved wire is then ready to be wound into spring-like coils. The most commonly used method is that wherein the tungsten wire is wound on a mandrel or core wire of steel. Some filament coils are wound with 2,065 turns per inch, which means that the turns are spaced at intervals of slightly less than 1/2,000 inch. Since none of these turns, which are examined under a microscope, must touch or even vary perceptibly in spacing, machinery of the utmost precision is required.

After completion of the coiling operation, the drums on which the coils with the mandrels are wound are immersed in a solvent to remove any oil or grease. Next follows the annealing operation wherein heat is applied to the coil and its mandrel. This relieves strains and makes the tungsten wire stay set. The wire and its mandrel are then cut into proper lengths, according to the type of lamp for which the coil is to be used.

The next operation consists of dissolving out the mandrel wire (figure 6). Here the coils are immersed alternately in successive steps in acid and hot and cold water. Minus their mandrels, the coils are baked in hydrogen gas. They are then optically inspected (figure 7), the smaller sizes with a special projector by means of which an image of the coil enlarged 60 times is projected on a screen (figure 8).

In the most commonly used types of general lighting service lamps, the filament consists of one continuous

helical coil. For other types of lamps, it is necessary to wind the coils in sections. These sectional coils are then formed into hundreds of different sizes and shapes to meet the requirements of the great variety of lamps in which they are to be used. In order to prevent fracture of the cold tungsten wire, it is formed by bending it over a small electrically heated bar.

"LEAD-IN" WIRES

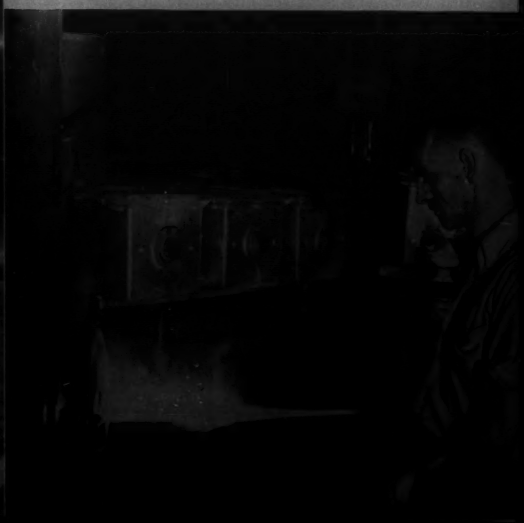
The wires for conducting the current from the base through the glass bulb to the filament of the lamp are commonly known as "lead-in" wires. Each such wire usually consists of three separate pieces of wire electrically welded into one composite piece. A typical lead-in wire for a gas-filled or Mazda *C* lamp is made of nickel, copper, and "dumet" (dual metal—a copper-coated steel wire with the same coefficient of expansion as the glass in which it is to be imbedded). The nickel is that part of the wire exposed to the inert gas inside the bulb. It is connected to the "dumet" which passes through the glass to the copper wire leading to the base. "Dumet" has replaced the platinum wire used in the early incandescent lamps.

Figure 1. Tungsten ore is analyzed to detect impurities, passes through a variety of chemical treatments to transform it to yellow tungstic oxide

Figure 2. First filtered, tungstic oxide then is dried in steam kettles and ovens

Figure 3. One stage in the treatment of tungsten powder is its formation into bars 24 inches long by 3/8 inch square under a hydraulic pressure of about 20 tons per square inch; the brittle bars are then baked and subjected to high electric currents

Figure 4. Heated in an electric furnace, the tungsten bar is swaged into a rod which gradually diminishes in diameter as it increases in length and tensile strength



FILAMENT SUPPORTS

Inasmuch as the wires supporting a lamp filament reach a high temperature when the lamp is lighted, they necessarily must be made of a material having a high melting point. Molybdenum, having a melting point of 2,625 degrees centigrade, is most commonly used for this purpose, but tungsten or a two-piece support of nickel and molybdenum also may be used. The variety of types of Mazda lamps has required the design of many sizes and types of filament supports.

GLASS

In the making of lamps, some 40 different kinds of glass are used. The characteristics of a glass depend upon the proportion of the ingredients used in its manufacture.

Figure 5. Tungsten wire, reduced to a diameter of about ten mils by being drawn through dies of composition metal, is given its final roundness and diameter by diamond dies

Figure 6. First wound on steel mandrel wires into coils, the coiled tungsten wires, which have been cut into the lengths required for various types of lamps, are immersed successively in acid and hot and cold water to dissolve out the mandrels

Figure 7. Finished tungsten coils are inspected individually

Figure 8. Smaller sizes of tungsten coils are inspected with a projector which produces an image 60 times the size of the coil

Figure 9. "Slip-over" coils are placed over the straight ends of filament coils for high-wattage lamps, to provide greater strength at the point where the lead-in wires are clamped to the filament

Figure 10. The filament and supporting parts of a lamp are first assembled, then the glass bulb is placed over this "mount" and gas flames applied to seal the two together. Unused portion of the bulb falls off

Among the characteristics which concern the Mazda lamp manufacturer are softening point, uniformity of expansion, electrical resistance, color, ability either to absorb or permit the passage of radiations of certain wave lengths. For example, one type of glass is used where high temperatures are encountered, while another answers the requirements of certain types of ultraviolet lamps, where it is desired to absorb some of the shorter wave lengths and pass the visible light and the longer wave lengths in the ultraviolet range. In other specialized types of lamps, the desire is to absorb as much of the visible light as possible, but at the same time allow the passage of the invisible ultraviolet rays. For this purpose, a dark-colored glass, known as a "black" glass, is used.

Some 300 sizes and shapes of bulbs are received from the glass factory, and a much greater number of sizes and types of cane glass and glass tubing are also used. The proper selection, inspection, and use of glass in the incandescent lamp industry is an art in itself.

BASES

The manufacture of lamp bases requires knowledge of metal forming, stamping, drawing, and glass working. The principal raw materials used in base manufacture are sheet brass and glass. Although there are some 30 different styles and sizes, the larger percentage of general lighting service lamps is confined to types using the medium-screw and the mogul-screw bases.

The problem of base manufacture is one of the oldest in the electric lamp industry. In the earlier days, means had to be provided immediately for connecting the lamp to the lighting circuit. The type of base and socket screw shell which Edison devised has been used for nearly 60 years without any fundamental change. National standards have been adopted for the miniature, candelabra, intermediate, medium, and mogul screw-thread types. Bases are manufactured in accordance with these standards, so as to assure their satisfactory use with the corresponding sockets which likewise have been standardized.

GAS

In addition to the millions of cubic feet of illuminating gas consumed annually in the various heating and glass-working operations, lamp manufacture also involves the use of other gases, some of them rare and little known. Among these gases are hydrogen, oxygen, nitrogen, argon, neon, helium, and krypton. Hydrogen and oxygen gas are manufactured in the lamp factory by electrical decomposition of water. Other gases of standard commercial grades are obtained by fractional distillation of liquid air. These gases are subjected to elaborate purification and drying processes prior to being sealed in the lamp.

The most commonly used Mazda *C* general-lighting-service lamps have bulbs filled with a mixture of argon and nitrogen gases to about 0.65 of atmospheric pressure. In normal operation, because of increased temperature, this pressure is slightly below atmospheric. Other lamps use one of these gases alone, while some of the more specialized types utilize the rarer gases. The proper

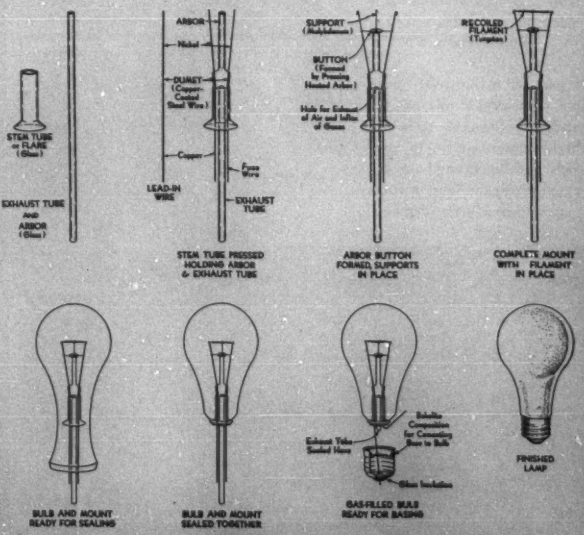

STEM TUBE or FLARE (Glass)
EXHAUST TUBE AND ARBOR (Glass)
ARBOR
Nickel
DUMET (Copper-Coated Steel Wire)
Copper
Cross Wire
LEAD-IN WIRE
EXHAUST TUBE
STEM TUBE PRESSED HOLDING ARBOR & EXHAUST TUBE
SUPPORT (Nickel-plated)
BUTTON (Formed by Pressing Heated Arbor)
Hole for Exhaust of Air and Inflow of Gases
ARBOR BUTTON FORMED, SUPPORTS IN PLACE
RECOILED FILAMENT (Tungsten)
COMPLETE MOUNT WITH FILAMENT IN PLACE
BULB AND MOUNT READY FOR SEALING
BULB AND MOUNT SEALED TOGETHER
Exhaust Tube Sealed Here
Shellac Composition for Cementing Base to Bulb
Glass Insulation
GAS-FILLED BULB READY FOR BASING
FINISHED LAMP

Figure 11. Steps in assembling mount and completed Mazda lamp

performance of a Mazda *C* lamp depends in a large measure upon the purity and freedom from moisture of the gas or gases with which its bulb is filled.

ASSEMBLY

The first step in the assembly of the various parts that make up a finished Mazda lamp is the preparation of the "mount," which consists of the filament and the supporting parts. The flare, the combined arbor and exhaust tubing, and the lead-in wires are grouped in proper relation to each other and gas flames applied to the assembly. The heat softens the two glass parts, causing them to fuse together with the dumet of the lead-in wires embedded in the glass. Then two jaws apply pressure to the softened glass, forming what is known as the "press." While the glass is still soft, a blast of air is blown down the exhaust tubing causing a hole to open through one face of the press. It is through this hole that air is pumped from the bulb and afterwards the filling gas allowed to enter.

The end of the glass arbor then is softened by gas flames and slightly upset, to form the "button". Into the still-soft glass of the button the support wires are inserted. Following this, the ends of the lead-in wires are flattened and bent at the point where they are to be clamped to the filament. The clamping of the filament and the coiling of the support wires, pigtail-like, around the filament coil completes the mount.

In the next operation, the glass bulb is placed over the mount (figure 10) and the gas flames applied to the neck of the bulb at a point opposite to the flare inside the bulb. The softened glass of bulb and flare fuses together and the unused end of the bulb or "cullet" falls off, completing what is known as "sealing in." During this operation, while the glass is still soft, shoulders are formed on the bulb to provide a seat for the base. This makes for accurate over-all length of the lamp and insures precision alignment of the axis of the base with the axis of the bulb, as well as stronger basing.

Next follows one of the most exacting operations in lamp making in which rotary slide valves finished to optical flatness are used in the process wherein the air is removed from the bulbs, and, in the case of the Mazda *C* lamp, replaced by gas. The sealed-in bulbs with the exhaust tubes connected to vacuum line ports are passed through gas flames. The resulting high temperature vaporizes any moisture in the bulbs. The vaporized moisture and most of the air is withdrawn by a vacuum pump.

The bulbs then are flushed out with an inert gas as many times as necessary to assist in removing residual vapor. In the final stage, the bulbs are filled with the required amount of the desired gas and "tipped off" by fusing the exhaust tube.

"GETTERS"

The amount of air left inside the lamp after it is sealed is very small, comparatively speaking, being less than 50 microns, or about 0.00007 of atmospheric pressure. This, however, is still too much for a good lamp. Consequently, "getters" are used to remove the last measurable trace of the remaining air. A getter is a mixture of chemical substances, the action of which is best understood by considering what takes place in a vacuum, or Mazda *B*, lamp. The getter is placed on the filament during the fabrication of the lamp. When the lamp is first lighted, the getter is vaporized and dispersed from the filament. It combines chemically with some of the gases, and, broom-like, sweeps the rest before it, impinging them on the bulb surface and holding them there permanently. This process "cleans up" the residual undesirable gases, water vapor in particular, in the bulb, giving a much better vacuum and producing a good condition for the operation of the filament. In Mazda *C* or gas-filled lamps, the getter's chief function is to clean up the water vapor.

The getter in a Mazda *B* lamp has still an important function to perform after it comes to rest on the bulb. The layer of getter, so formed, is not sufficient to absorb appreciable light. It provides an irregular or increased surface area as a reception place for the black particles of tungsten emitted from the filament while the lamp is operating. So the black particles, instead of falling on a smooth hard surface and making a continuous layer of metal which would absorb light, stagger themselves and bury themselves irregularly in the layer of getter, thus creating an effect similar to venetian blinds, and allowing the light to pass through. This effect of getter action greatly retards the blackening of the bulb, and hence increases the average light output throughout the life of the lamp.

BASING

Following the "tipping off" operation, the sealed-in bulb is ready for application of the base. Contrary to a rather general belief, the base has no part in the airtight sealing of the bulb, but merely supports the bulb and provides a means of connection between bulb and socket.

Preliminary to its cementing to the bulb, the base is filled with a soft cement consisting of some seven ingredients. One of these is a fugitive dye that lends a

Figure 12. Mazda Service inspectors, in addition to lighting sample lamps, check electrical characteristics and light output, dimensions, alignment, and other details

greenish hue to the cement. Upon application of the proper temperature for the required length of time, the green color fades, and the cement assumes a brown color. In the basing operation, the base is placed on the bulb with one of the lead-in wires protruding through the center eyelet and the other wire lying between the bulb and the edge of the base. The cement having hardened from application of heat, the ends of the lead-in wires are cut off and the wires automatically soldered to the base. Both the solder and the soldering flux used must meet definite specifications as to chemical content. During the period in which lamps are on the basing machine, they are lighted five different times. They are again lighted and inspected prior to final packing.

MAZDA SERVICE INSPECTION

The finished lamps are then placed on a conveyor in unsealed cartons and are required to pass in parade, so to speak, before the eyes of Mazda Service inspectors supervised by the Electrical Testing Laboratories of New York. Each package is subject to inspection and sample lamps are selected at random and given a thorough inspection (figure 12). In addition to the lighting of the lamp, this inspection includes a check of electrical characteristics and light output, over-all length, light-center length, base alignment, strength of the bond between base and bulb, and an inspection of details of the base, the bulb, and the mount.

OTHER INSPECTIONS AND TESTS

In addition to the tests and inspections of lamp parts and finished lamps already enumerated, each manufacturing division maintains a photometric and life-test department where representative quantities of lamps from current production are checked for light output and for life. Quick results on these life tests are obtained by burning the lamps at overvoltage—the ratio between the life at this voltage and the life at normal voltage being known. For example, certain types of lamps designed for 1,000 hours average life at normal voltage could be expected to last an average of 5 hours when operated at 50 per cent overvoltage. By means of such forced tests it is possible to keep a daily check on the quality of lamps as they are manufactured without the delay incidental to testing at normal voltage.

Selections of lamps from the various manufacturing divisions are sent to the central life-test department, where, after "seasoning," the lamps first are measured for electrical characteristics and light output by means of photoelectric-cell photometers accurate to less than one fourth of one per cent. The lamps are then placed on test racks, patrolled at least once each half-hour, where they are operated to burn-out, most at normal and a few at forced voltage, on a circuit where the voltage is allowed to vary not more than one tenth of one per cent.

As a lamp burns, there is a certain depreciation in light output caused by bulb blackening, resulting from the normal deposit of sublimated tungsten. A check on the rapidity and amount of this depreciation is determined by photometry of the lamps at various stages during life.

After completion of these tests, the lamps are carefully inspected by representatives of the manufacturing and engineering departments and a record made of the types of failure and their causes. This information is valuable in maintaining and improving the quality of the Mazda lamp.

The life-test department also is provided with equipment for testing lamps under conditions simulating those in actual usage. Racks arranged for producing vibration of varying amplitudes and frequencies assist in the development of lamps best suited for use under vibration conditions such as are encountered in many industrial plants. The susceptibility of a lamp filament to shock is determined by means of the "bump" tester wherein the lamp is attached to a cord and is allowed to swing in an arc and make impact against a board at the lowest point of the arc. The greater the length of the swing necessary to break the filament or the bulb, the greater the strength of the lamp. Other lamps are tested in equipment where shock from battleship gun-fire is simulated.

Shipping strength of lamps and suitability of packing materials are determined on the "package drop tester" by means of which handling and shipping conditions are duplicated. This quick test is later checked by actual freight or express shipment.

Traveling inspectors check and inspect lamps in warehouses, to make sure not only that they are made right, but also that they *stay* right. Inspections also are made and records kept of the performance of thousands of lamps used under actual service conditions. The success of the quality safeguards used in Mazda lamp manufacture is indicated by the fact that inspection of millions of lamps shows serious defects in only about one tenth of one per cent.

Ultraviolet on a Dairy Farm

At Broadacres Farm in Lebanon, N. J., extensive use of ultraviolet radiation is reported to be producing milk of a superior quality—a bacteria count of less than 1,000 per cubic centimeter whereas grade A pasteurized milk allows for 30,000 bacteria per cubic centimeter and grade B 100,000. Two two-hour sunbaths per day—one beginning at five in the morning and the other beginning at six in the evening—are given to all milk cows through the medium of *S*-4 lamps hung on six-foot centers eight feet above the floor down the main aisle of the barn.

General lighting for service maintenance in the barn is provided by fluorescent lamps in simple fixtures appropriately placed.

A liberal installation of germicidal lamps is reported to protect completely every step in the handling, processing, and bottling of the milk. It is said that the milk is never exposed except under direct radiation from germicidal lamps, and that the same type of equipment continually sterilizes the bottles, bottling machines, and cans.

Abstracted from "I Believe in Ultraviolet," *The Magazine of Light*, volume 10, 1941, number 5, pages 26–7.

Progress in the Art of

Metering Electric Energy

IV—Calibration and Installation of Watt-Hour Meters

This article concludes the series on the metering art sponsored by the AIEE committee on instruments and measurements; the complete report is being issued in pamphlet form for immediate distribution, details on page 597

A VITAL ASPECT of the art of metering electric energy is the calibration, installation, and maintenance of the meter that measures this energy. This constitutes an important contact between the utility company and its customers. The diligence with which, since the origin of the art, methods and techniques have been developed and pursued to insure a high degree of accuracy has done much to create on the part of the customer a feeling of confidence in the meter by means of which his charge for the service rendered is computed.

CALIBRATION OF THE WATT-HOUR METER

In most states periodic testing of watt-hour meters is required by law. The period between tests varies, but six-year periods are common practice at present and longer ones are contemplated. If a meter is removed or damaged, or if there is a complaint from a customer, it may receive special tests between the periodic ones.

Tests that can be performed in a laboratory or shop may utilize procedures and equipment not generally applicable to tests made on the customer's premises. It is obvious that test equipment for field use must be primarily portable and self-contained. However, a test, whether in or out of the laboratory, must consist of comparing the performance of the meter to be tested with a certain established standard of performance.

In the very early days calibration of the meter was a major problem, because suitable standards of comparison were not available. At first indicating instruments were used exclusively for calibrating purposes. In order to make a complete calibration, it was necessary to measure voltage, current, watts, and time.

Standardization is important in the manufacture of any electrical equipment but it is obviously of special importance in the manufacture of watt-hour meters. From the beginning, the manufacturers set up standardizing laboratories in which fundamental standards were maintained in close calibration with those of the National Bureau of Standards. Each employed the best techniques then known to make their manufactured product conform to these standards. It must be understood that in the very early days of the art primary, secondary, and working standard instruments, as these are known today, were not available and the problem of standardization was a major one.

Prior to 1900, voltage was measured with a Cardew hot-wire voltmeter (figure 32). Current was measured by means of the Siemens dynamometer (figure 33), or a Kelvin balance (figure 34). Power was measured by the Siemens watt-dynamometer or the Kelvin watt-balance. Figure 35 shows an improved dynamometer-type instrument known as a "precision wattmeter" developed in 1904 by the Westinghouse company. It is a modified Kelvin balance. Time was measured with a stop watch. Frequency in those days was determined by means of a steel wire stretched in the field of an a-c electromagnet. The vibrating length of the wire was varied to secure resonance by use of a rider, and the frequency measured with a stationary scale graduated in "alternations per minute."

By 1897 the Weston Electrical Instrument Corporation had developed a "direct reading" portable wattmeter and its voltmeter. These instruments were push-button-damped at intermediate deflections but were undamped when taking the final reading. Thus with variations in supply voltage, and undamped instruments, the calibration of watt-hour meters in the early days was an exceedingly tedious process.

The uniform calibration of these early indicating standards presented an additional problem. They could not be transported to and from the National Bureau of Standards without their calibration being impaired. Moreover, they all had serious temperature errors. This condition compelled all the manufacturers to establish and maintain their own standardizing laboratories. Such laboratories are equipped to check the indicating standards against primary standards. Standard cells, standard resistances, and other fundamental standards are checked with the National Bureau of Standards at regular intervals. Standards laboratories are maintained as separate units from the main production laboratory.

This report was initiated and sponsored by the AIEE committee on instruments and measurements as part of its regular activities for 1940-41, under the following direction: I. F. Kinnard, West Lynn, Mass., chairman; A. S. Albright, Detroit, Mich., vice-chairman; T. S. Gray, Cambridge, Mass., secretary. Personnel of subcommittee on watt-hour meters: A. S. Albright, chairman; D. T. Canfield, Lafayette, Ind., editor-in-chief; A. L. Brownlee, Chicago, Ill.; A. B. Craig, Boston, Mass.; J. S. Cruikshank, Baltimore, Md.; C. L. Dawes, Cambridge, Mass.; A. P. Good; Stanley Green, Lafayette, Ind.; F. C. Holtz, Springfield, Ill.; H. C. Koenig, New York, N. Y.; Paul MacGahan, Newark, N. J.; C. V. Morey, New York, N. Y.; H. C. Rankin, Boston, Mass.; A. R. Rutter, Newark, N. J.; F. B. Silsbee, Washington, D. C.; G. R. Sturtevant, Lynn, Mass.; and H. L. Thomson, Hartford, Conn.

Figure 32. The Cardew hot-wire voltmeter, instrument used before 1900

Figure 33. A Siemens dynamometer

Figure 34. A Kelvin watt-balance

Figure 35. Dynamometer-type precision wattmeter

The early experience of the utilities followed closely that of the manufacturers, and many embarrassing questions arose as to whether the utility or the manufacturer was correct. In some instances standards were shipped back and forth in an attempt to establish comparisons. The difficulties of the early days are suggested by figure 36 which reproduces a photograph (exact date not known) of the "meter shop" of the Commonwealth Edison Company of Chicago, Ill. Considering the type of surroundings and the equipment available it is surprising that the quality of the work done was as good as it was.

The next major improvement in the testing of watt-hour meters was the introduction of the rotating standard by the Westinghouse company in 1899. Early forms of this instrument consisted of a regular watt-hour-meter unit mounted in a box having a suitable case and handle. The disk shaft extended into the lid of the box and was equipped with a sweep hand which revolved over a circular scale divided into 100 equal parts. The total number of whole revolutions was recorded on a separate dial. Thus any number of revolutions of the rotating standard could be determined to 1/100th part of a revolution for any given number of revolutions of the meter being tested.

In 1903 W. J. Mowbray designed and built the first multiple-range rotating standards. These test meters had two voltage ranges and three to five current ranges. The first d-c rotating standards could not be operated by opening and closing the potential circuit but the a-c rotating standards were operated that way from the beginning.

The meter being tested, the rotating standard, and a suitable load all are connected in series. In the simplest case, where the test constants of the meter and standard are identical, a test would be made in the following manner. The standard is run for the exact length of time that it takes the meter to run a specified number of revolutions, say 20. If, for example, the standard runs more than 20 revolutions, the meter being tested is slow and must be adjusted until the revolutions of both meters are the same. Practically all field testing is done this way, and all but the larger companies use this technique in their meter shops and laboratories. This method of testing greatly speeded up the calibration procedure, since any fluctuations in load affected meter and standard alike, and therefore did not alter the result. The accuracy of the standard was maintained by checking it with indicating instrument standards which in turn were checked against primary standards in the standardizing laboratory.

A modified form of the rotating standard was used in the production laboratory by the manufacturers. Test boards or panels were developed to speed up the operation. Gang testing also came into existence. In such arrangements two or more meters were tested at one time, with or without automatic starting and stopping. Master clocks with contacts frequently were used to determine the time interval.

In several instances the improvements already mentioned in the development of the watt-hour meter were first applied to the rotating standard, and only later to the general production of watt-hour meters. In any

event, improvement in the rotating standard at least kept pace with the general advance of the art.

In 1925 development in electronic devices had progressed to the point where the possibility of their use as auxiliaries in the testing process gave promise of both greater speed and greater accuracy. The first recorded device of this character was developed in 1925 by A. R. Rutter of the Westinghouse Electric and Manufacturing Company. This particular arrangement focused a light beam through holes in the meter disk upon a photoelectric cell, which in turn caused marks to be printed on a tape upon which a time scale was placed from contacts on a master clock. Thus the speed of the disk could be determined without actually counting the revolutions.

Some two years later H. P. Sparkes, also of the Westinghouse company, suggested the use of the stroboscopic principle as a method of calibrating watt-hour meters. The principle of the stroboscope may be applied to testing meters in several different ways. Basically, however, the method consists in cutting a number of evenly spaced teeth (for example, 400) on the periphery of the disk, or marking the disk with equally spaced lines, and focusing upon these markings a beam of light that is interrupted at a known rate or turned on or off at a known rate. By such an arrangement it is possible to cause the disk to appear to stand still at the speed at which the meter is correctly calibrated. If the disk appears to drift backward the meter is slightly slow and if it appears to drift forward the meter is slightly fast. Thus the meter may be adjusted visually without the necessity of counting the revolutions.

The larger utilities which have a huge number of meters to handle have found it economical to build and maintain well-equipped establishments for their meter departments. Figures 37 and 38 illustrate what some of the larger utilities are doing. These photographs show the meter laboratories of The Detroit Edison Company, Detroit, Mich. Figure 37 shows the section of the a-c standards laboratory where the rotating standards are checked periodically; figure 38 a section of the main production laboratory with gang testing in operation.

Many of the larger utilities are using the stroboscope in their production laboratories. The fact that meters of more than one manufacture, and therefore of more than one basic test constant, are involved complicates the arrangement somewhat, but the underlying principle is the same as that previously described. Figure 39 shows a stroboscope installation used by the Commonwealth Edison Company, Chicago, Ill.

Some utilities have developed testing boards that are essentially fully automatic. In figure 40 is shown a panel of this kind developed by the Pennsylvania Power and Light Company, Allentown, Pa. The left-hand dial at the bottom sets the test constant for the meter being tested. The right-hand dial at the bottom makes the necessary connection for a two- or three-wire meter of any number of terminals. Immediately above the two bottom dials is a voltage-selector switch and above that is a current-selector switch. The push buttons on the right-hand edge of the panel are the adjusting and starting switches. Relays control the sequence of the operations, the necessary adjustment of the disk to zero, and so on. When the proper test constants, connections, voltage, and load have been selected, the starting button is pressed and the test proceeds under completely automatic operation until it is completed. The resultant registration of the meter is indicated on the appropriate large dial on the upper left-hand side of the panel. If adjustments are necessary, they are made, and the operation is repeated until the desired accuracy is obtained.

One type of test made exclusively by the utilities is that made on the customer's premises. In the very early days this was a difficult and tedious process, but with the development of the rotating standard both difficulty and tediousness were greatly reduced. There still remained, however, the problem of providing a suitable load for the meter. At first the customer's load was used, but since this could not be controlled properly, it was generally unsatisfactory. To avoid the problems involved in using the customer's load, the practice of isolating the meter from this load by by-passing the feeders around the meter during the test became general. Artificial loads then were used in making the test. At first variable resistors of one form or another were used. Later the so-called phantom load came into wide use. This device is an application of the transformer principle to the creation of the desired current at low voltage for testing purposes. It is small, compact, and of light-enough weight to be carried easily by the tester.

The testing of d-c meters was accomplished from the beginning by the use of variable rheostats for meters of

Figure 36. Early meter shop and laboratory of a public utility

Figure 37. Shop testing division of a public utility, modern installation

low rating and by storage batteries when the rating was large. This practice is still in use today and for large-capacity meters requires a considerable number of storage batteries with the necessary transportation to and from the installation.

INSTALLATION OF THE WATT-HOUR METER

Progress has been made in the technique of installing the meter as well as in its manufacture and calibration. In figure 41 is shown an early installation, which in the light of present practice may be described as being everything it should not be. This installation "just grew." There is no indication of a plan and no attempt at protection either of life or of property. In fact, one is forced to conclude either that electric codes were nonexistent or that inspection was reprehensibly lax. Yet to the meterman the picture has a strange fascination. Contrast this picture with figure 42, which shows a modern, completely inclosed indoor installation. In a space little larger than that used for the old installation are 31 meters, each with properly sealed test facilities. In figure 43 is shown a still more modern installation, employing socket-type meters with enclosed test facilities. Here also is illustrated a meter tester at work under conditions that are conducive to high-quality results, obtained with maximum safety for both the tester and the property.

The progress which these pictures illustrate was made possible principally by two factors: a basic change in the National Electrical Code, and the standardization of meter-terminal dimensions and arrangements.

Until about 1931 the Code required that a switch and a main-line fuse be placed between the supply and the meter. Such an arrangement limited the installation largely to indoor arrangements, besides creating a number of complications when more than one meter and service were connected to a single entering circuit. Since access to the line ahead of the meter was at least possible in the old sequence, attempts were made in the early days to seal switches and even fuses, but such practices were generally unsatisfactory. About 1931 the Code was changed to permit the installation of the meter ahead of the switch and fuses. This sequence was a much simpler arrangement, and also removed any possible temptation on the part of an unscrupulous customer to connect loads ahead of the meter.

The standardization of the meter-terminal dimensions and arrangements in 1934 also helped along the progress of standardized meter installations. Meters of any manufacture could be mounted interchangeably, as far as meter trims, test facilities, and conduit arrangements were concerned.

The development and more general use of meter-testing devices has increased greatly the safety of the meter tester,

Figure 38. The a-c standards laboratory of a public utility

particularly in respect to power metering at high voltages. Where such devices are economically feasible accidents are reduced materially and much time is saved. Many such devices have been designed, to meet a multiplicity of conditions, but, in general, they consist of switching arrangements which disconnect the meter from the customer's load and at the same time connect that load through to the line and afford access to the meter terminals for test purposes.

Figures 43 and 44 illustrate two such devices. The one in figure 44 is a power-metering installation requiring instrument transformers (not shown) and demand meters. The two meters on the left center of the board are printing-type demand meters. The device just above the tester's head is a demand-totalizing relay. It is used for the purpose of totalizing demand impulses from contactors in each of the four polyphase watt-hour meters shown on the board, adding these impulses, and delivering the result to one of the demand meters. The composite demand of the four circuits being metered is then printed on the tape of the latter. This demand meter is a class II meter, as described in part III of this report.

Figure 41. Early meter installation

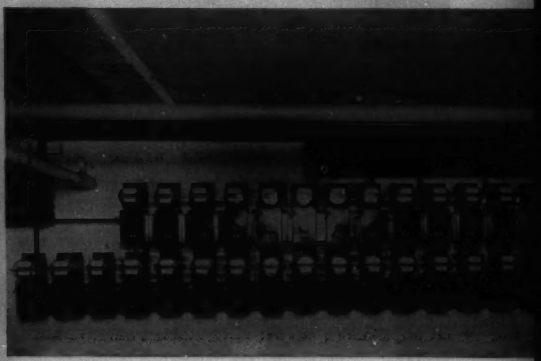


Figure 42. Modern meter installation

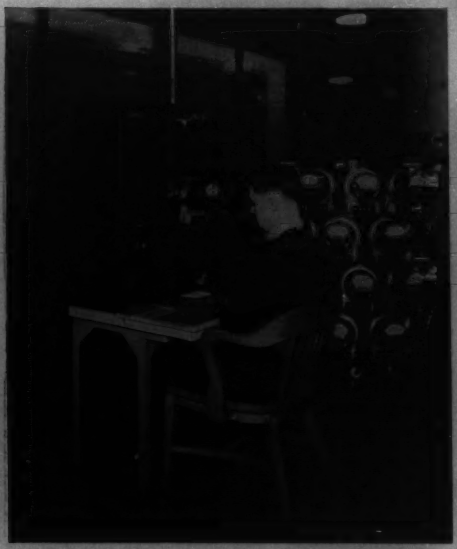


Figure 39 (above). Strobometer

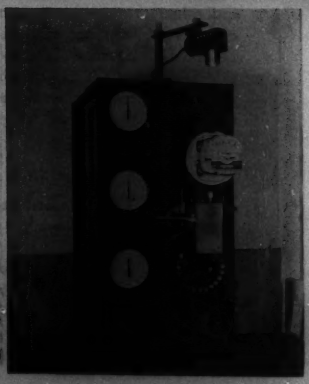


Figure 40. Automatic testing unit

The introduction of a temperature-compensated, weatherproof meter, combined with the revision of the Electrical Code, made outdoor metering physically and economically feasible. One form of such installation before and after a changeover from indoor to outdoor metering is illustrated in parts (*a*) and (*b*) of figure 45. In (*b*) an outdoor meter of the *A*-base type is used in conjunction with a protector case. Figure 45 (*c*) illustrates another method of outdoor metering where a socket-type meter is used without any additional protection being required.

Many different arrangements of meter installations could be illustrated, but the typical examples mentioned

Figure 43 (left). Modern meter installation with built-in test facilities

Figure 44 (below). Modern power-metering switchboard installation

are sufficient to show the progress in this phase of the art. However, occasional installations that have not been modernized are still to be found. Rehabilitation and modernization of meter installations of necessity must lag considerably behind development, for obvious economic reasons.

CONCLUSION

This report has dealt with 60 years of progress in the art of measuring electric energy. Measurement is essential to the progress of any industrial art but the measurement of electric energy was of particular importance to the development of the process of supplying this energy for the improvement of human welfare.

Because this art is more directly affected by economic and sociological trends than are many other industrial arts, its progress has been more difficult to depict. A great diversity of interests was involved in its growth. Such bodies as the national meter committees of the Edison Electric Institute and the Association of Edison Illuminating Companies have had a particularly noticeable influence upon its development.

The nature of this report is such that the operating engineers cannot be given individual recognition, but collectively they are entitled to and should receive a considerable share of the credit for the progress that has been made in the art of metering electric energy.

(a) (b) (c)

Figure 45a. Old-style service drop with indoor metering

Figure 45b. New-style service drop with outdoor metering; meter has protector case

Figure 45c. Outdoor metering with socket meter

Appendix. Guide to Sources of Supplementary Information on Metering

BOOKS

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ELECTRICAL MEASURING INSTRUMENTS, two volumes, C. V. Drysdal and A. C. Jolley. D. Van Nostrand Company, New York.

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HISTORY OF THE ELECTRIC LIGHT, H. Schroeder. The Smithsonian Institution, Washington, D. C., 1923, 94 pages.

THE MEASUREMENT OF ALTERNATING-CURRENT ENERGY, D. T. Canfield. McGraw-Hill Book Company, New York, 1940, 210 pages.

MEASURING INVISIBLES. Weston Electrical Instrument Corporation, Newark, 1938, 51 pages.

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MUSEUMS AND COLLECTIONS

Professor Elihu Thomson Collection, General Electric Company, West Lynn, Mass.

Duncan Memorial Museum, Purdue University, West Lafayette, Ind.

Ford Museum, Dearborn, Mich.

Smithsonian Institution, Washington, D. C.

Science Museum, South Kensington, London, England

Meter Patents Listed in the Patent Office Gazette

Some of the more important patents issued to inventors, with brief descriptions of some specifically mentioned in the text or of particular historical interest. Those chosen show important steps in the advancement of the watt-hour meter art, or establish important dates

Name	Patent No.	Date	Description
Gardiner, Sawyer, Fuller and Forbes			
S. Gardiner, Jr.	132,569	October 29, 1872	These devices were all similar to Gardiner's number 1 claim: "1. The combination and arrangement of an electromagnet and its armature with the releasing device of a clock mechanism for indicating upon a dial the time during which an electrical current is in action"
W. E. Sawyer	210,151	November 19, 1878	
J. B. Fuller	210,316	November 26, 1878	
G. Forbes	366,824	July 19, 1887	

Meter Patents Listed in the Patent Office Gazette (Continued)

Name	Patent No.	Date	Description
Edison			
T. A. Edison	240,678	April 26, 1881	"A Weber Meter." Two plates in an electrolyte balanced on a rocking beam. When one plate receives a sufficient deposit of, say, copper it tips the balance in its direction thereby reversing the current through the electrolyte and recording the result on a dial. The process is then repeated in the opposite direction
	242,601	June 14, 1881	A motor meter driving a fan for a load
	248,565	October 18, 1881	Device for decomposition of water, arranged so that the gases released actuate a recording mechanism
	251,545	December 27, 1881	An electrolytic cell in conjunction with an electromagnetic recording mechanism
	251,557	December 27, 1881	Two electrolytic cells, one to operate at a faster rate (across a higher resistance shunt) than the other. Means of heating the electrolyte to keep resistance of shunted circuit constant. One cell was intended to be used for a check meter on the other. This is similar to the meter described in part I of this series of articles (*EE, Sept. '41, p. 421*)
	251,558	December 27, 1881	Antifreezing resistances claimed
	281,352	July 17, 1883	Amalgamated electrodes, zinc, claimed. Reduction of losses in the meter
Weston and Mott			
Edward Weston Samuel Mott	282,428	July 31, 1883	First recorded patent of the men who later founded the Weston Electrical Instrument Corporation
Thomson			
Elihu Thomson	381,441 381,442 381,443	April 17, 1888	Patents for the rocking-beam meter consisting essentially of two glass bulbs connected by a glass tube all mounted on a beam pivoted at the center. Each bulb had a heating element through which the current to be measured passed, first in one bulb, then the other. The heat generated expanded the gas in the bulb, forcing a liquid into the other bulb and thereby rocking the beam in that direction. The process switched the current to the filled bulb and repeated the process. These three patents were followed by some 12 or 15 others covering improvements on this meter. The last of these was issued about 1890
	444,930	January 20, 1891	With this patent Thomson seems to have abandoned the rocking-beam meter and switched to the commutator-type-motor meter. It was filed in 1890. This first patent used electromagnetic retardation
	448,894	March 24, 1891	Permanent magnet retardation used here
	508,661	November 14, 1893	Patent on voltage transformer called a "converter" used in the potential circuit of Thomson's commutator-type-motor meter. Perhaps the first instrument transformer ever used. Also indicates that his meter would operate on alternating current. Followed by many others covering improvements thereon
Aron and Siemens			
H. Aron	374,860	December 13, 1887	Patent covering Aron's pendulum meter, one of the most accurate d-c energy-measuring meters ever designed
E. W. Siemens	415,577	November 19, 1889	Commutator-type motor meter
DeFerranti, Hookham, Halsey, Gutmann, and Lanphier			
S. Z. DeFerranti George Hookham E. S. Halsey L. Gutmann and R. C. Lanphier R. C. Lanphier	338,588 579,582 626,832 738,902 843,155	March 23, 1886 March 30, 1897 June 13, 1899 September 15, 1903. February 5, 1907	The DeFerranti patent discloses the Faraday disk or mercury-motor meter; the Hookham patent is for another mercury motor meter. The five patents listed here represent the backbone of the mercury-motor meter art. All the present meter manufacturers and several others at one time or another obtained patents on a meter of this type. Lanphier of the Sangamo Electric Company seems to have been the only one to persist and eventually to produce an accurate and reliable meter of this type
Shallenberger			
O. B. Shallenberger	388,003	August 14, 1888	Patent covering the first induction-type meter in the United States; its number 1 claim reads: "1. The combination of a rotating armature, an inducing circuit polarizing said armature when traversed by alternating electric impulses, a second inducing circuit receiving currents from the first circuit and polarizing said armature in a different direction, and a counting, registering, or indicating device actuated by the movements of the armature"
	388,004	August 14, 1888	Describes some alternative ways of obtaining a shifting field, the use of a shunt coil to overcome friction or to furnish a wattmeter element. Also illustrates the use of reactors and capacitor to produce fluxes out of phase with each other, but apparently not, at that time, in the sense of lagging
	414,595	November 5, 1889	Adds transformer with taps to increase range
	419,367	January 14, 1890	Improvements in construction and movable secondary inducing circuit to adjust speed for a given current
	448,676	March 24, 1891	The inventor seems to have been much worried by what he called "leakage currents," which today would be called exciting currents. The meter was evidently being used on the primary side of distribution transformers and, of course, read even when no lights were turned on the secondary side. To cause the meter to fail to respond on the "leakage currents of the converter" but to respond when any light was used on the secondary of the "converter" the armature of the meter (disk) was flattened on two sides. This patent was followed by several others using electromagnetic and other schemes for the same purpose
	531,866 531,867	January 1, 1894 January 1, 1895	Patents covering the watt-hour meter—the substitution of coils of wire for the short-circuited secondary or inducing circuit, and the connection of these coils for both potential and current
	548,231	October 22, 1895	Apparently the first patent disclosing the use of a short-circuited coil and series resistance for phasing purposes; represents Shallenberger's most important contribution to the metering art
	591,240	October 5, 1897	Improved means of phasing a meter
Slattery			
M. M. Slattery	404,801	June 4, 1889	Same principle as Shallenberger's meter, but used extra heavy copper grids for the secondary coil
	410,880	September 10, 1889	Overload compensation applied by counterbalanced split vanes which operated by centrifugal force
Duncan			
T. Duncan	500,958	July 4, 1893	Multiphase meter. Refers to an application filed December 21, 1891, serial No. 415,825, giving the principle of the meter
	501,000	July 4, 1893	Describes early air-vane meter mentioned in text
	518,311	April 17, 1894	D-c-motor meters used on alternating current. Shows use of instrument transformers
	523,704	July 13, 1894	Addition of core in secondary to improve torque
	550,823 551,436	December 3, 1895	Improvements
	560,087	May 12, 1896	Winding of secondary with wire and connecting it in shunt thus making a watt-hour meter. This patent was followed in close order by 25 or 30 patents covering both d-c and a-c meters
	753,193	February 23, 1904	First patent issued to Duncan's Lafayette residence
Gutmann			
Ludwig Gutmann	543,089	July 23, 1895	An air-vane induction-type lamp-hour meter
	614,225	November 15, 1898	Improvement of slanting slots in barrel-like drum used for disk

Meter Patents Listed in the Patent Office Gazette (Concluded)

Name	Patent No.	Date	Description
Conrad, Davis, and Bradshaw			
H. P. Davis and F. Conrad	608,842	August 9, 1898	Show method of measuring energy in a three-phase, four-wire system using three current transformers (secondaries in delta) and a two-element polyphase meter
F. Conrad	716,867	December 30, 1902	
W. Bradshaw	807,435	December 19, 1905	Casing and terminal blocks.
Wood and King			
J. J. Wood	442,501	December 9, 1890	A rocking-beam meter
	469,800	March 1, 1892	A meter which is fundamentally wrong in principle
E. J. King	671,282	April 2, 1901	Describes type *K* meter
	727,640	May 12, 1903	Type *K* meter with forms of potential shunt
J. J. Wood	780,769	January 24, 1905	Correct principles in this meter
Kennelly, Oxley, and Steinmetz			
A. E. Kennelly	479,167	July 19, 1892	A motor meter with drag coil in series with the armature
C. P. Steinmetz	539,452	1895	Two-element d-c meter of commutator type
E. Oxley	588,170	August 1897	Both of these patents covered multi-rate meters
	593,852	November 16, 1897	
C. P. Steinmetz	780,769	August 1, 1905	Shaded pole meter
Pratt, Vaughen, Lunt, Alton, Vogel			
W. H. Pratt	590,648	September 28, 1897	A d-c two-element meter
	645,125	March 13, 1900	Starting coils, consisting of a coil in series with the potential coil to start a meter. First form of light-load or friction compensation. Early coils were not apparently adjustable
F. G. Vaughen	678,075	July 9, 1901	A bent iron-wire clip put on edge of disk to prevent creeping. Apparently first anti-creep device
A. D. Lunt	696,459	April 1, 1902	Copper squares "pasted" on disk to act as anti-creep devices
G. H. Alton	733,611	July 14, 1903	Improvement in jewel mountings
W. H. Pratt	711,932	October 11, 1904	Another form of starting coil
	816,375	March 27, 1906	Two-and-one-half-element meter for use on three-phase four-wire systems. The equivalent of Conrad's three-current transformer scheme
	835,321	November 1906	Covers the first adjustable light-load plate used
F. M. Vogel	941,436	November 30, 1909	Covers a lag plate
W. H. Pratt	984,297	February 14, 1911	Covers grid mounting of the elements in a meter
	1,003,031	May 20, 1913	Improved light-load and lag plate
Lanphier			
R. C. Lanphier	1,010,271	November 28, 1911	Covers the type *H* meter
Harris			
J. Harris	543,865	August 6, 1895	Combination graphic and watt-hour meters
	583,000	August 21, 1900	A summation meter
Stanley			
W. Stanley, Jr.	494,513	March 28, 1893	A two-coil a-c mter
	588,666	August 24, 1897	The magnetic flotation meter
Scheeffer			
G. A. Scheeffer	522,674	July 10, 1894	Early model of Diamond Meter Company meter. Used a cup disk and air-vane damping
	530,351	December 4, 1894	Later model of Diamond Meter Company meter
	591,641	October 12, 1897	Four-magnet meter
	599,302	February 15, 1898	D-c meter
	643,162	February 13, 1900	Round-type Diamond meter
	905,934	December 8, 1908	Inclined-coil type. Columbia Meter Company
	950,074	February 22, 1910	Assigned to General Electric Company
	995,637	June 20, 1911	Columbia Meter Company
	1,082,653	December 30,1913	Roller Smith Company meter
Bláthy, Batault, Tollie, Boddie, Bradshaw, Knight, Kurz			
O. T. Bláthy	423,210	March 17, 1890	Meter with two or more electromagnets one set shunt and the other series, offset from each other with respect to a disk upon which drag magnets also operate
B. Batault	693,537	February 18, 1902	Diverter or saturable member for improving characteristics
O. T. Bláthy	716,372	December 23, 1902	Improved pole tips and magnetic circuits
	853,216	May 14, 1907	Various shunts and special pole pieces for improving load curves
H. Tollie	1,155,384	October 5, 1915	An *L*-shaped bracket placed on both current and voltage magnet to compensate for overloads. A form of saturable member
C. A. Boddie and W. Bradshaw	1,285,911	November 26, 1918	Overload compensation devices
C. A. Boddie	1,290,492	January 7, 1919	Another form of saturable member for overload compensation
J. A. Knight	1,299,736	April 8, 1919	Another form of saturable member for overload compensation
F. Kurz	1,727,509	September 10, 1929	Another form of saturable member for overload compensation
Kinnard and Green			
I. F. Kinnard	1,706,171	March 19, 1929	Temperature compensation with negative temperature coefficient material in shunt with the permanent magnet
Stanley Green	2,110,417	March 8, 1938	Discloses the use of the laminated noninterfering disk for use in single-disk polyphase meters
	2,110,418	March 8, 1938	Discloses the first use of Alnico magnets in watt-hour meters
	2,203,411	June 4, 1940	Patent on new pivot material called Permalloy for use in watt-hour meter pivots
Wright, Mers, Luckee, Steele, Karapetoff, Hall, Mowbray			
A. Wright	702,844	June 17, 1902	Early form of Wright demand meter
	702,847	December 23, 1902	Wright demand meter of the form still used in this country
C. H. Mers	722,030	March 3, 1903	Discloses underlying principle of demand meters
W. W. Luckee and D. J. Steele	933,845	September 14, 1909	Mechanical device embodying all essentials of modern demand meter except clock timing of interval
V. Karapetoff	972,538	October 11, 1910	Demand meter using clock, which may be set for any time interval desired. Several additional features not used on modern indicating block-interval demand attachment
C. F. Hall	1,028,715	June 4, 1912	Five-minute block-interval demand of present type, in which Hall refers to C. H. Mers's work of 1903
W. J. Mowbray	1,024,218	April 23, 1912	Temperature-compensated rotating standard for d-c meters

Ten Years of Progress in Relaying

This is the second of a series of three related articles which together present a review of the progress made in the past decade in the protection of electric power-system circuits and equipment. This article, concerned with protective relaying, has been prepared under the auspices of the AIEE committee on protective devices. The first article of the series, concerned with circuit-interrupting devices, was published last month; the third, dealing with lightning-surge protective devices and the protection of systems against lightning, is now in preparation and is scheduled for publication in a later issue.

JUDGING from the external appearance of relays, one might conclude that protective relaying was an unromantic and prosaic subject. Here are a lot of little devices that spend most of the time sitting still, with not even the little eye-appeal of the moving pointer of an instrument or the passing black spot on the disk of a watt-hour meter. Yet compacted within these small cases is the fruit of the labor of many minds, in such form that, when called upon to function, relays take a set of observations, perform a lightning calculation, and act, all within 1/20 of a second.

Put in more technical terms, the general objectives of protective relaying are: (*a*) the limitation of damage to electric equipment, and (*b*) the maintenance of adequate service with reasonably low investments in generation, transformation, transmission, and distribution equipment. In order to obtain these objectives, the protective-relay system must detect positively the occurrence of a short circuit, determine enough about its location to permit selection of the breakers which must be opened, and control the opening of only those breakers necessary to remove the fault from the system—all in a time short enough to limit equipment damage and reduce system disturbances to a reasonably low value.

In a period of a little more than ten years, a major change has been made in protective-relay methods. From the standpoint of the electrical industry, probably the greatest significance of the change is that modern relaying methods make possible the rendering of improved service with a lower investment in major electric equipment, resulting in savings that many times exceed the total cost of the protective relays.

Previous to 1930, most relay applications for line protection used overcurrent and directional relays with graded time delay to obtain selectivity. As a result the time required to clear many system faults was a matter of seconds. As systems became more complex two limitations of the graded time overcurrent relays became apparent. One was that the prolonged duration of faults sometimes resulted in loss of system stability; the other that, when the maximum load current equaled or exceeded the minimum fault current, overcurrent relays were unable to distinguish between load and short-circuit currents.

During the period since 1930 selectivity has been improved somewhat but the chief improvement has been in speed of operation. The trend has been definitely toward the provision of means whereby at least the more severe faults will be cleared in relay times of the order of one to three cycles. This has brought about the development of new relay systems, such as distance relays and pilot-relays, and also of many new relay elements. These new devices have a much higher torque-inertia ratio than the familiar induction disk formerly used and therefore are inherently much faster in operation.

The relays and relay systems developed during the past ten years and now in common use have two outstanding characteristics. First, if a fault occurs in the area protected by a given relay, the relay operates to energize the breaker trip circuit in a time of the general order of one to three cycles. Second, the relays are capable of distinguishing between load currents and fault currents despite wide variations in system generating capacity. These developments, combined with the parallel development of high-speed circuit breakers, have made it possible so to protect a transmission system that any line fault will be cleared in a total time of ten cycles or even less.

The new relays for line protection may be divided into two classes, the distance relays and the pilot relays. Distance relays may be of either the impedance or reactance type. Pilot relays may operate over physical pilot wires with a-c or d-c excitation, or may use carrier current over the line conductors themselves.

While most of the changes of the past decade have affected line relaying, some marked improvements have been made in relays for apparatus and bus protection, characterized largely by developments making possible faster operation.

The trend in relaying in the immediate future seems to be toward simplification and improved reliability rather than toward any fundamental changes in relays or systems, or in speed of operation. Considerable interest exists in the possibility of using vacuum tubes for relaying. Such use remains a distinct future possibility, and the increasing need for more sensitive devices may result in the development of radically new relay devices for such purposes. Some of the fields where more sensitive operation

might prove helpful are ground protection, bus protection, and pilot-relay systems.

DISTANCE RELAYS

The distance relays used before 1930 were not of the high-speed variety. They were so designed that the time of operation was a direct function of the distance from the relay to the fault. This form of time-distance characteristic produced satisfactory selectivity, but was not suitable for high-speed relaying.

The modern high-speed relay is set to operate on its so-called instantaneous time for any fault within 80 per cent of the protected line section. The so-called instantaneous time step is of the order of one cycle in actual practice. For faults beyond the 80 per cent of the line covered by the instantaneous element, a definite time is introduced into the relay system sufficient to permit a similar relay to clear selectively in the first zone in case the fault is beyond the next station.

The step-distance-time curve can be obtained with relays which have measuring elements operating either to measure impedance or reactance. Both types have been used very widely, although most applications have provided protection only for faults involving more than one phase, that is, either phase-to-phase or three-phase faults. While the theoretical possibilities of applying the step-distance characteristic for single-phase-to-ground faults have long been known, there has been relatively little application in this field because of the variations in distance measurement introduced by ground fault conditions and the cost.

PILOT-WIRE PROTECTION

At the beginning of the last decade, pilot-wire protection of transmission lines was essentially similar to differential protection of generators or transformers, in that the actual secondary output of the current transformers at the two ends of the line was compared physically at a relay having the necessary interconnecting pilot wires. This system not only required a costly multiconductor pilot wire, but imposed a very high burden on the current-transformer system so that accuracy was impaired, and in addition required continuous integrity of the pilot-wire circuit.

Two main developments have characterized this past ten-year period. One is the development of the so-called directional-comparison type of pilot-wire system, whereby the indications of directional relays at the two ends of the transmission line are compared over a physical pilot wire operating as a simple d-c telegraph circuit. In its simplest conception, the contacts of the two directional relays, one at each end of the line, are inserted in series in the pilot-wire circuit and the connections of the relays so made that for any internal fault causing power to flow into the section at both terminals, both relays will close contact and thereby energize the pilot-wire circuit, and in turn cause the tripping of the oil circuit breakers.

The other development has been made possible through the availability of new relay elements requiring materially less energy for operation. It is now possible to supplant the multiconductor pilot wire of the earlier differential systems with a single telephone pair. High-speed differential relays responding to all types of faults are now available for the protection of transmission lines of reasonable length over a conventional telephone pair. Special applications have been made successfully on lines as much as 25 miles long.

Both these systems have been widely used, and have been shown through adequate operating experience to be thoroughly reliable. With either the d-c or the a-c system, tripping times of the order of one to three cycles are now readily available.

CARRIER-CURRENT PROTECTION

The first carrier-current relay system was described before the Institute in 1928. This system proposed to simulate the multiple-conductor pilot systems then in use, and to compare the phase relationships of the currents in the two ends of the line by means of 60-cycle modulation of the carrier system. A number of installations made in 1929, for protection against ground faults only, gave satisfactory results. Attempts in the earlier days of the development to make the system operative on all types of faults were not successful because the power requirements of the relay system at that time were greater than the available output of current transformers.

Subsequently, the comparison of phase relationship of currents was discarded in favor of a comparison of power direction at the two ends of the line similar to the system described for the d-c pilot system. As used today, the carrier impulse is a means of preventing tripping whenever an external fault occurs. In case of an internal fault, directional relays at the two ends of the line, operating in response to power flow into the line, turn off the carrier signal and thereby permit tripping. The relay systems now in use turn on carrier immediately whenever a fault occurs, whether internal or external to the line section, and the carrier subsequently is controlled by the operation of the directional relays to allow or prevent tripping as the fault location dictates.

Improvements in the design of equipment and circuit-control features have permitted a reduction in operating time from between 15 and 30 cycles with the original system to between 1 and 3 cycles with the modern system. Two types of equipment are in use. One consists of simple fault-detecting relays for turning on the carrier signal and directional relays for controlling the signal once started in response to a fault. This system functionally provides the equivalent of differential protection and is operative only in case of internal faults. The other system builds up carrier control about the elements commonly used for distance protection, and embodies in one set of equipment not only the advantages of differential protection for internal faults but also the step-distance characteristic operative as a back-up for external faults when necessary.

INSTANTANEOUS OVERCURRENT RELAYS

While there is nothing essentially new about an instantaneous overcurrent relay, elements of this type have found new application in the last ten years. On many systems it has been found practical to add instantaneous overcur-

rent relays to the graded-time overcurrent relays used for selectivity. These instantaneous relays are given a setting in current value just in excess of the maximum current which could be transmitted to a fault at the remote end of the line that they are protecting. Such relays may be used for phase-to-phase-fault protection or ground-fault protection. It is sometimes necessary to use a directional element in addition to the instantaneous relays to secure proper selectivity on lines forming part of a network. Operating experience has indicated that on some systems where generating conditions are relatively constant, from 80 to 85 per cent of all faults can be cleared by the action of these relays, which have an operating time of about one to three cycles.

BUS PROTECTION

The desirability of always providing automatic protection to remove any type of fault from the system has become much more generally appreciated in the past decade. As a result many bus sections previously left unprotected are being provided with protective relays. The most popular method of protection is the one involving the differential connection of all current transformers in all primary connections to the given bus section. Differential protection of this type may employ either standard-speed induction overcurrent relays or high-speed relays of the multiple-restraint or harmonic-restraint types. Since the application of high-speed relays requires a complete study of current-transformer characteristics, a more thorough investigation and a more complete understanding of the phenomena involved in current-transformer operation, particularly under transient conditions has resulted. Special current transformers capable of maintaining ratio characteristics up to more than 100,000 amperes have been developed for bus-differential purposes.

In certain cases distance relays have been employed to good advantage where feeder reactors are utilized. Fault-bus systems have been employed whereby the fault current to ground resulting from a fault on the protected section is made to flow into the fault bus where its presence can be detected and the desired relay operation performed.

SENSITIVE GROUND PROTECTION

Considerable study has been devoted to the problem of relaying distribution circuits in case of accidental ground. A paper[1] recently presented before the Institute describes a system developed and applied to an ungrounded system. Research has been carried on in the development of a relay system responsive to arc frequencies in connection with high-resistance ground fault. Although many problems remain to be solved, the studies being made in various quarters hold promise that an adequate relay system for the detection of these troublesome faults eventually will be developed.

HIGH-SPEED RECLOSING

High-speed-reclosing relays have been developed for the protection of distribution circuits which, together with instantaneous tripping, permit clearing of temporary faults before the branch fuses blow and the re-energization of the circuit with a total outage time of less than a second.

The reclosing systems also provide that the instantaneous tripping will not be in service on delayed reclosures, so that if the short circuit is of a permanent nature the branch fuses will limit the interruption to a single section. As a result, almost as good service can be provided with relatively inexpensive fuses as would be obtained by the installation of oil circuit breakers and control equipment at each branch sectionalizing point.

The use of pilot wire or carrier current relaying insures simultaneous opening of the breakers at each end of a tie line so that there is no danger of either breaker reclosing before the arc has been de-energized. This scheme of protection and reclosing may make a high-voltage transmission line so reliable as to make unnecessary or to defer the construction of an additional transmission line.

BIBLIOGRAPHY

No references have been cited in this summary of trends in relaying during the past ten years, because a "Bibliography of Relay Literature, 1927–1939" has been prepared by the relay subcommittee of the AIEE committee on protective devices and issued as a special Institute publication.*

1. Sensitive Ground Protection for Radial Distribution Feeders, L. F. Hunt and J. H. Vivian. AIEE Transactions, volume 59, 1940 (February section), pages 84–90.

* Copies of the "Bibliography of Relay Literature," published July 1941, may be obtained from AIEE headquarters, 33 West 39th Street, New York, N. Y., at a cost of 25 cents per copy to Institute members or 50 cents to nonmembers.

20,000-Kva Synchronous Condenser

Photo courtesy General Electric

Recently installed at the Denver terminal of the Public Service Company of Colorado, this 13,800-volt synchronous condenser is hydrogen-cooled, and operates at 900 rpm

Institute Activities

Contents of December 1941 Supplement

SUPPLEMENTING the technical papers that have been preprinted from the 1941 volume of AIEE TRANSACTIONS in the monthly TRANSACTIONS sections of ELECTRICAL ENGINEERING for July to December inclusive, a December 1941 "Supplement to ELECTRICAL ENGINEERING—TRANSACTIONS Section" is being issued. This is the second supplement to be issued in 1941, the first being the June 1941 supplement. Both represent the operation of the improved publication procedure adopted at the 1940 AIEE summer convention (*EE, Aug. '40, p. 331–2*).

The December 1941 supplement will contain 32 technical papers and all discussions of these papers and of the papers preprinted in the July–December monthly sections. This supplement, like that of June 1941, will be greatly oversize in order to complete the transition from the previous publication procedure within the current year. Under the present procedure, all papers presented during a calendar year will be contained in the annual volume for that year and preprinted in the monthly sections and semi-annual supplements.

Copies of the December 1941 supplement will be mailed when ready to those who entered advance orders. Others may obtain copies at 50 cents each ($1.00 each outside the United States and possessions) from the AIEE order department, 33 West 39th Street, New York, N. Y., as long as the limited supply lasts.

Abstracts of the papers in the current supplement have appeared in the news pages of ELECTRICAL ENGINEERING, where they were published in advance of the meetings and conventions at which the papers were presented, in accordance with the provisions of the current publication policy. Papers appearing in the December 1941 supplement, with references to their abstracts, are:

Basic Sciences

41-103—A Short Method for Evaluating Determinants and Solving Systems of Linear Equations With Real or Complex Coefficients; *Prescott D. Crout (M'41).* May 1941, page 230.

41-105—Diode-Rectifying Circuits With Capacitance Filters; *D. L. Waidelich (A'39).* June 1941, page 290.

41-107—Analytical Methods of Solving Discrete Nonlinear Problems in Electrical Engineering; *E. G. Keller (M'40).* June 1941, page 290.

Communication

41-20—Basic Principles of the Varioplex Telegraph; *Philo Holcomb, Jr. (M'41).* January 1941, page 35.

41-42—Television Transmission Over Wire Lines; *M. E. Strieby (F'41) and J. F. Wentz (A'24).* January 1941, page 35.

41-47—Rural Automatic Telephone Networks; *C. F. Ffolliott (M'38).* January 1941, page 35.

Electrical Machinery

41-84—Methods of Determining Natural Frequencies in Coils and Windings; *L. V. Bewley (M'37), J. H. Hagenguth (A'28), and F. R. Jackson, Jr. (A'40).* April 1941, page 180.

41-85—Surge Characteristics of Two-Winding Transformers; *Reinhold Rüdenberg (M'38).* April 1941, page 180.

41-126—Transient Torques in Squirrel-Cage Induction Motors, With Special Reference to Plugging; *E. S. Gilfillan, Jr., and Edward Kaplan.* June 1941, page 290.

41-139—Self-Excitation of Induction Motors With Series Capacitors; *C. F. Wagner (F'40).* August 1941, page 406.

41-167—Alcoa Rectifier Installation; *J. E. Housley (M'39) and H. Winograd (M'39).* November 1941, page 553.

Electronics

41-50—A Thyratron Circuit for Theater Lighting; *Carl R. Wischmeyer (A'40).* January 1941, page 36.

Industrial Power Applications

41-67—Short-Circuit Calculating Procedure for Low-Voltage A-C Systems; *A. G. Darling.* January 1941, page 37.

Instruments and Measurements

41-119—Power Circuit Instruments for the Higher Range of Audio Frequencies; *L. J. Lunas (M'36) and Paul MacGahan (M'15).* June 1941, page 292.

Land Transportation

41-101—Electric Locomotive Application; *E. W. Brandenstein (M'37) and D. R. MacLeod (A'33).* May 1941, page 230–1.

Power Transmission and Distribution

41-26—Powerton-Crawford 220-Kv Line; System Operating Features and Terminal Design; *H. E. Wulfing (M'23) and T. G. LeClair (F'40).* January 1941, page 39.

41-57—Powerton-Crawford 220-Kv Line; Design and Construction Features; *M. S. Oldacre (A'13) and F. O. Wollaston (A'27).* January 1941, page 40.

41-73—Stability Limitations of Long-Distance A-C Power Transmission Systems; *Edith Clarke (M'33) and S. B. Crary (M'37).* January 1941, page 39.

41-74—System Lower Harmonic Voltages—Methods of Calculation and Control by Capacitors; *W. C. Feaster and E. L. Harder (M'41).* January 1941, page 40.

41-95—The 220,000-Volt System of the Hydro-Electric Power Commission of Ontario—II; *A. H. Frampton (M'28) and E. M. Wood (M'35).* May 1941, page 231.

41-97—Measurement and Control of Conductor Vibration; *Gordon B. Tebo (A'36).* May 1941, page 231.

41-141—Lightning Strokes in Field and Laboratory—III; *P. L. Bellaschi (F'40).* August 1941, page 407.

41-148—An Analysis of Transient and Sustained Voltages in Ground-Fault Neutralizer Systems; *S. B. Farnham (A'36), E. M. Hunter (M'36), and H. A. Peterson (M'41).* August 1941, page 407.

41-165—Tennessee Valley Authority Hydroelectric Stations—Electrical Design; *Raymond A. Hopkins (M'19).* November 1941, page 553.

41-166—Operation of Load-Ratio-Control Transformers Operating in Parallel and in Networks; *F. M. Starr (M'37).* November 1941, page 553.

Production and Application of Light

41-123—The Incandescent Lamp Situation From the Engineering Point of View; *Preston S. Millar (M'13).* June 1941, page 292.

Protective Devices

41-65—Prolonged Inrush Currents With Parallel Transformers Affect Differential Relaying; *C. D. Hayward (M'41).* January 1941, page 41.

41-100—Field Investigations of Lightning; *C. F. Wagner (F'40), G. D. McCann (A'38), and Edward Beck (M'35).* May 1941, page 231.

41-122—D-C Machine Flashover and Bus Short Circuit Protection; *T. B. Montgomery (M'41) and J. F. Sellers (A'34).* June 1941, page 293.

41-128—**Protection of Low-Voltage Circuits by Air Circuit Breakers in Cascade Arrangement;** *A. E. Anderson (F'40) and C. H. Black (A'41).* June 1941, page 293.

41-135—**New Current Transformer for Bus Differential Protection;** *L. F. Kennedy (M'39) and A. T. Sinks (A'36).* June 1941, pages 292–3.

Safety

41-7—**Electric Shock;** *C. F. Dalziel (M'39), Doctor John B. Lagen, and J. L. Thurston.* January 1941, page 41.

Winter Convention Program to Reflect Concern With Defense

Tentative arrangements for the winter convention, which will be held in New York, N. Y., January 26–30, 1942, with headquarters in the Engineering Societies Building, indicate that a timely program of broad interest is being developed. Preliminary plans provide for a general session, 18 technical sessions, and several conferences, to be held during the mornings and afternoons, while the evenings will be taken up with a smoker, Edison Medal presentation, and a dinner-dance. Special entertainment for women guests will be arranged by the women's entertainment committee, under the chairmanship of Mrs. G. S. Rose.

Among the 18 technical sessions, several will reflect the part being taken by different branches of the profession in national defense. The educational session will have papers dealing with the changes in engineering curricula and advanced training in the graduate field to meet the needs of the emergency. A symposium on electric power distribution systems in the current national defense program will present the steps being taken by several operating companies. Another symposium on asynchronous machines, which will treat the precise speed control of these large motors with variable-speed drive, represents the research and development angle. Other sessions of broad popular interest will deal with the subjects of lightning investigations in the field and distribution switching and relaying.

The general session will be devoted to a topic of timely importance designed to interest as many members as possible.

The members of the 1942 winter convention committee are as follows:

D. A. Quarles, *chairman;* J. W. Barker, T. F. Barton, G. E. Dean, E. B. Dorting, J. F. Fairman, L. C. Miller, D. H. Moore, J. H. Pilkington, C. S. Purnell, and W. W. Truran. *Chairmen of subcommittees:* S. B. Graham, *dinner-dance;* J. R. McCormack, *smoker;* R. F. Brower, *inspection trips;* and Mrs. G. S. Rose, *women's entertainment.*

Board of Directors Meets

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on October 24, 1941.

A budget for the appropriation year beginning October 1, 1941, was adopted as recommended by the finance committee.

Upon invitation of the Vancouver Section and the District officers concerned, authorization was given to hold the 1942 Pacific Coast convention of the Institute in Vancouver, B. C., September 9–11. A joint conference on student activities of Districts 8 and 9 and the University of British Columbia Branch was authorized to be held in Vancouver during the 1942 Pacific Coast convention.

Approval was given to the dates, April 29 to May 1, 1942, for the North Eastern District meeting previously authorized to be held in Schenectady, N. Y.

Upon recommendation of the executive committee of the North Eastern District and the Sections committee of the Institute, the board authorized the following assignment of territory in that District to Sections in New York State and New England:

State of New York

St. Lawrence County assigned to the Syracuse Section

Franklin and Clinton Counties assigned to the Schenectady Section

State of Vermont

Addison, Chittenden, LaMoille, Franklin, and Grand Island Counties assigned to the Pittsfield Section

Washington, Orange, Caledonia, Essex, and Orleans Counties assigned to the Springfield Section

State of New Hampshire

Grafton County assigned to the Worcester Section, Coos and Carroll Counties assigned to the Boston Section.

Upon recommendation of the standards committee, the board took the following actions:

Approved a revision of the Standard for Railway Motors (AIEE Standard No. 11), developed by a sectional committee under the sole sponsorship of the AIEE and approved by the AIEE committee on land transportation, and its transmittal to the American Standards Association for approval as an American standard.

Approved, for publication as an AIEE standard, a report on "Standards for Wet Tests," developed by a special subcommittee.

Approved the appointment of the following Institute representatives:

C. H. Anderson, Sectional Committee on Definitions of Electrical Terms

R. G. McCurdy, chairman, **H. M. Turner** member of AIEE delegation on Sectional Committee Z24, Acoustical Measurements and Terminology (the former succeeding P. L. Alger, who remains a member of the committee, and the latter succeeding Bassett Jones, resigned)

Royce E. Johnson on Section Committees C70, C71, and C72—Domestic Electric Flatirons, Household Electric Ranges, and Electric Water Heaters, respectively.

The following amendments to the Institute bylaws were adopted, in order that they

In Memoriam

BANCROFT GHERARDI

THE death, on August 14, 1941, of Bancroft Gherardi removed from the membership of the Institute its 40th president and a leading pioneer in the development of electrical communication, with a career of more than 40 years in that field.

Doctor Gherardi received the degree of bachelor of science from the Polytechnic Institute of Brooklyn in 1891, the degree of mechanical engineer from Cornell University in 1893, and the master's degree in mechanical engineering from that university in 1894. He received the honorary degree of doctor of engineering from the Polytechnic Institute of Brooklyn, 1933, and from the Worcester Polytechnic Institute, 1936.

In 1895, he was employed by the Metropolitan Telephone and Telegraph Company. He was engineer of the traffic department 1900–01, and was transferred to the position of chief engineer of the New York and New Jersey Telephone Company in 1901. In 1906, he returned to New York as assistant chief engineer of the New York Telephone and Telegraph Company and the New Jersey Telephone Company. He was appointed engineer of plant of the American Telephone and Telegraph Company in 1907, became acting chief engineer in 1918, and chief engineer in 1919. From 1920 until his retirement in 1938, he was vice-president and chief engineer.

He joined the Institute in 1895, and was transferred in 1904 to the grade of Member and in 1912 to the grade of Fellow. He served on many AIEE committees, and represented it on various joint organizations. He was a manager 1905–08, and 1914–17, vice-president 1908–10, and president 1927–28.

RESOLVED: That the board of directors of the American Institute of Electrical Engineers, upon behalf of the membership, hereby expresses sincere appreciation of Doctor Gherardi's numerous contributions, during his membership of 46 years, to the development of Institute activities, and deepest regret at his death, and be it further

RESOLVED: That these resolutions be entered in the minutes and transmitted to the members of Doctor Gherardi's family.

—AIEE Board of Directors, October 24, 1941

might conform with the action of the board of directors on August 8, 1941, abolishing two committees, and with the present rules of the John Fritz Medal Board of Award:

Sec. 85—General Committees. The following committees were deleted: "Committee on Legislation Affecting the Engineering Profession", "Committee on Economic Status of the Engineer".

Secs. 74 and 83 (pertaining to the two former committees mentioned above). Deleted.

Sec. 92—John Fritz Medal. The words "October first" substituted for the words "the third Friday in October" in the second sentence, thus changing that sentence to read: "Each year the President, on October first, shall become a representative of the Institute on the Board of Award of the John Fritz Medal, and the functions of the senior past president of the Institute on this Board shall then cease and determine."

In accordance with section 22 of the by-laws, five members of the board of directors were selected to serve as members of the national nominating committee, as follows:

T. F. Barton, Mark Eldredge, F. Malcolm Farmer, T. G. LeClair, L. R. Mapes; Everett S. Lee and K. L. Hansen *alternates*.

The following additional appointments were made:

H. S. Osborne, an AIEE representative on the Standards Council of the American Standards Association, three-year term beginning January 1, 1942; H. E. Farrer, R. E. Hellmund, and E. B. Paxton *alternates for 1942*.

John C. Parker, Institute representative on the Hoover Medal Board of Award, for term ending May 1943, succeeding Doctor William McClellan, resigned.

A resolution in memory of Past President Bancroft Gherardi, who died on August 14, 1941, was adopted (page 594).

Other actions taken by the board included the following:

Minutes of the meeting of the board of directors held on August 8, 1941, were approved.

The following actions of the executive committee as of September 16, 1941, were reported and confirmed: 5 applicants transferred to the grade of Fellow; 29 applicants transferred and 16 elected to the grade of Member; 57 applicants elected to the grade of Associate; 24 Students enrolled.

Reports of meetings of the board of examiners held on September 11 and October 23, 1941, were presented, and the recommendations adopted at those meetings were approved. Upon recommendation of the board of examiners, the following actions were taken: 9 applicants were elected to the grade of Member; 42 applicants were elected to the grade of Associate; 585 Students were enrolled.

Monthly expenditures were reported by the finance committee, and approved by the board, as follows: $21,144.46 in August; $24,940.28, September; $31,149.40, October.

Those present were:

President—David C. Prince, Schenectady, N. Y.

Past Presidents—F. Malcolm Farmer, New York, N. Y.; R. W. Sorensen, Pasadena, Calif.

Vice-Presidents—J. W. Barker, New York, N. Y.; J. L. Hamilton, St. Louis, Mo.; K. L. Hansen, Milwaukee, Wis.; N. S. Hibshman, Bethlehem, Pa.; J. Elmer Housley, Alcoa, Tenn.; Everett S. Lee, Schenectady, N. Y.; C. A. Price, Hamilton, Ont.; Walter C. Smith, San Francisco, Calif.

Directors—T. F. Barton, New York, N. Y.; M. S. Coover, Ames, Iowa; Mark Eldredge, Washington, D. C.; Lester R. Gamble, Spokane, Wash.; R. E. Hellmund, East Pittsburgh, Pa.; T. G. LeClair and L. R. Mapes, Chicago, Ill.; Fred R. Maxwell, Jr., Pensacola, Fla.; F. J. Meyer, Oklahoma City, Okla.; W. B. Morton, Philadelphia, Pa.; R. G. Warner, New Haven, Conn.

National Treasurer—W. I. Slichter, Schenectady, N. Y.

National Secretary—H. H. Henline, New York, N. Y.

Institute Finances as Reflected in 1941–42 Budget

At its meeting held on October 24, 1941, the board of directors received from the finance committee a report of the financial operations of the Institute for the appropriation year which ended September 30, 1941, and a recommended budget of income and expenditures for the ensuing year, which was adopted without change. This information is now presented to the membership in the form of a tabulation, with comparable figures for last year and with brief notes regarding those items which deserve special mention.

An increase over last year of 12 per cent in the page content of the TRANSACTIONS section of ELECTRICAL ENGINEERING, a similar increase in the amount of technical material to be published in advance-copy form for use at national and District meetings, one more District meeting than held last year, maximum financial support to Institute Sections under the existing by-laws, increased mileage allowance to delegates because of greater traveling distances to certain meeting places already announced, the restoration of funds for all national prizes, the addition to headquarters' staff of two persons who will serve in a junior clerical capacity, salary increases totaling $1,500 and affecting nine members of the staff—all

Institute Income and Expenses for the Year Ending September 30, 1941, and Budget for Year Ending September 30, 1942

	Actual Income and Expenses, Year Ending 9-30-41	Budget for Year Ending 9-30-42
Income		
Dues	$317,547.35	$324,000.00
Students' fees	13,355.70	13,000.00
Entrance and transfer fees	9,412.73	8,000.00
Advertising	49,788.59	50,000.00
ELEC. ENGG.—nonmem. subscriptions	13,277.52	10,000.00
TRANS. subscriptions	6,875.58	6,500.00
Miscellaneous sales	21,213.46	20,000.00
Interest on securities	6,472.02	5,500.00
Total	$337,942.95	$337,000.00
Expenses		
Publications:		
Text matter (ELEC. ENGG. & TRANS.)	$3,094.86	$ 82,410.00*
TRANS. SUPPLEMENT	2,125.01	1,700.00
Preprints	7,369.40	9,000.00
Advertising section—ELEC. ENGG.	22,477.83	23,450.00
Year Book	6,965.73	7,250.00
Miscellaneous expense	1,261.07	1,500.00
Institute meetings	13,485.24	15,150.00
Institute Sections:		
Appropriations	26,576.71	28,500.00
Other expenses	5,856.41	6,050.00
Institute Branches:		00
Meetings expenses	1,046.04	1,200.00
Other expenses	2,320.58	2,700.00
Committees:		
Code of prin. prof. conduct		50.00
Edison Medal	159.86	170.00
Finance	741.68	775.00
Headquarters	183.48	250.00
Lamme Medal	181.30	185.00
Membership	8,756.13	9,240.40
Pension Fund		500.00
Radio broadcasts	504.06	(see text)
Research		150.00
Standards	8,189.74	10,075.00
Technical committees	349.70	500.00
Traveling Expenses:		
Geo. Dist. exec. committees	3,091.94	4,000.00
Section delegates to summer conv.	5,624.96	5,250.00
Counselor delegates to summer conv.	892.94	750.00
Dist. secys. to summer conv.	393.56	750.00
District Student conferences	7,093.63	9,500.00
President's appropriation	960.44	1,000.00
Vice-presidents	697.51	1,000.00
Board of directors	6,808.73	8,000.00
National nominating committee	1,136.22	1,100.00
Past presidents and other AIEE representatives		500.00
Administration:		
Headquarters' salaries	36,273.67	38,585.00
Postage	4,331.46	4,500.00
Stationery & printing	3,824.02	4,000.00
Office equipment	443.93	1,000.00
Trav. expense, bank charges, insurance, misc. supplies and services	4,627.04	4,750.00
Paper prizes	553.05	850.00
Joint activities:		
American Engineering Council	2,075.00	
Amer. Co-ord. Com. Corrosion	25.00	25.00
American Standards Association	1,500.00	1,500.00
ECPD	850.00	1,700.00
Engg. Foundation research projects:		
Impregnated paper insulation	250.00	250.00
Insulating oils and cable saturants	250.00	250.00
Welding	250.00	250.00
Engg. Soc. Personnel Service, Inc.	1,245.45	1,200.00
Engg. Soc. Library	10,072.10	10,260.00
John Fritz Medal	50.00	50.00
N.F.P.A. Dues	60.00	60.00
United Engg. Trustees building assessment	10,984.81	10,985.00
U. S. Natl. Com. I.C.I.	300.00	300.00
Miscellaneous printing, etc.		6,000.00
Authors' reprints	3,902.28	
Reprints of standards	1,780.75	
Miscellaneous	1,082.56	
Other expenses:		
Membership badges	2,209.78	2,400.00
Legal services	250.00	250.00
Pension Fund Reserve	5,000.00	8,000.00
Prepaid ELEC. ENGG. expenses (text paper and env. in storage)	4,181.22	
Depreciation Reserve Fund	69.80	
Unappropriated:		
Reserved for contingencies and additional items		7,180.00
Total	$314,786.77	$337,000.00

*Actual amount available $86,591, including prepaid expenses.

Future AIEE Meetings

Southern District Meeting
New Orleans, La., December 3–5, 1941

Winter Convention
New York, N. Y., January 26–30, 1942

North Eastern District Meeting
Schenectady, N. Y., April 29–May 1, 1942

Summer Convention
Chicago, Ill., June 22–26, 1942

Pacific Coast Convention
Vancouver, B. C., September 9–11, 1942

these are provided for in the budget of expenditures. In addition, the annual appropriation for the proposed pension plan is increased from $5,000 to $8,000 to cover a preliminary estimate of the maximum probable amount of the annual accruing liability to the pension fund. The policy inaugurated last year of allowing for contingencies and probable additional items is continued, the budget including an unappropriated item of $7,180, from which the board subsequently appropriated $500 for radiobroadcasts to be sponsored by several of the engineering societies, and $200 toward the expenses of the Engineers Defense Board.

The increase of income necessary to carry this increased program comes principally through the larger membership of the Institute. The estimated income for the present fiscal year is practically the same as the actual income for the year which has just closed. This is because further increases resulting from continued increase in membership of the Institute during the current year are expected to be largely offset by losses in dues revenue from members now enrolled in military service, from overseas members, and from overseas subscriptions to Institute publications. Losses of this nature, which were not large in the last fiscal year, are expected to be considerably greater this year because of the increasing effect of war conditions.

The July issue of ELECTRICAL ENGINEERING carried in the news section (pages 336–50) the complete report of the Institute board of directors for the fiscal year ending on April 30, 1941, together with financial statements for the corresponding period. In this report will be found a comprehensive statement covering all activities of the organization, making it unnecessary to repeat at this time the details underlying appropriations for the principal activities. Should further information be desired, this can be obtained upon correspondence with Institute headquarters.

Dielectric Strength of Oil for Circuit Breaker Tests Approved

For some time a working group of the AIEE committee on protective devices has been actively studying the subject of the dielectric strength of oil for use when making impulse and low-frequency tests on oil circuit breakers. The results of this study were presented in a report at the 1941 AIEE summer convention, Toronto, Ont. ["Dielectric Strength of Oil for High-Voltage Testing of Oil Circuit Breakers," H. J. Lingal, W. F. Skeats, and H. D. Braley, AIEE TRANSACTIONS, volume 60, 1941 (September section) pages 903–06.] At its meeting of September 25 in Cleveland, Ohio, the committee on protective devices approved the recommendation of the working group (subcommittee on circuit breakers, switches, and fuses) for the use of oil having a dielectric strength of not less than 22 kv (measured under standard test conditions) in making impulse and 60-cycle tests.

The recommendation was made after considering the subcommittee's report, which described impulse tests on oils of different 60-cycle dielectric strength in both sample test gaps and full-size standard circuit breakers. The report showed that the impulse tests of oil circuit breakers were not appreciably changed by the presence of carbon and water in the oil. In some tests the impulse voltages required to break down the oil were higher for oils containing carbon and water than for new clean oil.

New Fault-Current-Calculating Procedure Recommended to Industry

A proposed new procedure for the calculation of short-circuit currents has been embodied in a report prepared under the auspices of the AIEE committee on protective devices, presented at the 1941 summer convention at Toronto, Ont., June 16–20, and published in the AIEE TRANSACTIONS, volume 60, 1941 (September section), pages 877–81. (Discussion of the report, also of interest, will appear in the 1941 TRANSACTIONS and in the December 1941 Supplement to Electrical Engineering —Transactions Section.) The committee urges the electrical industry to apply the new method and compare it with methods previously in use. Comments or suggestions will be welcomed, and should be sent to J. R. North, chairman, AIEE committee on protective devices, 212 West Michigan Avenue, Jackson, Mich., before May 31, 1942.

The precise determination of short-circuit currents involves a calculation so laborious as to be wholly impractical. Thus, some approximation is required, and a degree of judgment must be applied in any method proposed. The new method is based upon the determination of an initial value of rms symmetrical current with which multiplying factors are used for application purposes. It is proposed that this method be used where applicable, in place of the present method which involves the use of decrement curves. It is believed that the procedure is sufficiently accurate to serve as a reliable basis for the application of interrupting devices and for a preliminary setting for relays.

In the determination of this current, symbols are involved which have the following significance:

E = leg voltage
X_1 = direct axis reactance, either transient or subtransient as specified, in ohms/leg
X_0 = zero-sequence reactance
R_0 = zero-sequence resistance

Table I. Circuit Breakers, Protection Tubes, and Fuses

	Multiplying Factor	Reactance Quantity for Use in X_1: Synchronous Generator	Synchronous Motor	Induction Machine
A. Circuit-Breaker Interrupting Capacity				
1. General case				
Eight-cycle breaker	1.0	...Subtransient	..Transient	
Five-cycle breaker	1.1			
Three-cycle breaker	1.2			
Two-cycle breaker	1.4			
2. Short circuits fed predominantly by large machines at the point of fault may be increased up to 20 per cent				
3. Air circuit breakers rated 600 volts and less	1.25	...Subtransient	..Subtransient	..Subtransient
B. Mechanical Stresses and Momentary Rating of Circuit Breakers				
1. General case	1.6	...Subtransient	..Subtransient	..Subtransient
2. At 5,000 volts and below, unless current is fed predominantly by directly connected synchronous machines or through reactors	1.4			
C. Protector Tubes				
1. Maximum rating 2. Minimum rating—use minimum system capacity and minimum of E/X_1 or $3E/(2X_1+X_0)$	1.0	...Subtransient	..Subtransient	..Subtransient
D. Fuses				
1. General case	1.6	...Subtransient	..Subtransient	..Subtransient
2. At 15,000 volts or below with interrupting ratings not exceeding 3,000 amperes	1.2			

Table II. Relays

	Multiplying Factor	Reactance Quantity for Use in X_1: Synchronous Generator	Synchronous Motor	Induction Machine
1. High-speed current actuated	1.0	Subtransient	Subtransient	Subtransient
2. Time overcurrent	1.0	Transient	Transient	

The three-phase short-circuit current is $\frac{E}{X_1}$.

The line-to-line short-circuit current is $\frac{\sqrt{3}E}{X_1+X_2}$. Since X_2 is always at least equal to X_1, this quantity never exceeds 86 per cent of the three-phase short-circuit current and consequently may be neglected.

The line-to-ground short-circuit current is $\frac{3E}{X_1+X_2+X_0}$. Since X_2 is usually approximately equal to X_1, this expression is often shortened to $\frac{3E}{2X_1+X_0}$. In practical cases, regardless of the value X_2, this last expression also gives a satisfactory value for the current available from a double line-to-ground fault.

PROCEDURE

The following procedure gives a résumé of the various multiplying factors to be used with currents calculated by the formulas just stated, and Tables I and II show what reactance quantity should be used for representing the machines in the positive-sequence network.

Circuit Breakers, Protector Tubes, and Fuses. Determine "highest value of rms symmetrical current for any type of fault" by $\frac{E}{X_1}$ or $\frac{3E}{2X_1+X_0}$, whichever is greater, except that when R_0 is greater than $5X_1$ no consideration need be given to the latter term.

Basis for Preliminary Relay Settings. Two conditions should be determined for each class:

1. Maximum connected synchronous capacity and "the maximum initial symmetrical current" determined by $\frac{E}{X_1}$ or $\frac{3E}{2X_1+X_0}$, whichever is greater, except that when R_0 is greater than $5X_1$ no consideration need be given to the latter term.

2. Minimum connected synchronous capacity and "the minimum symmetrical current" determined by $\frac{0.866E}{X_1}$ or $\frac{3E}{2X_1+X_0}$, whichever is the smaller. Consideration should be given in particular situations to remote fault locations and fault resistance.

Report on the Metering Art to Be Issued as Pamphlet

The report on "Progress in the Art of Metering Electric Energy" sponsored by the Institute's committee on instruments and measurements, now being published serially in ELECTRICAL ENGINEERING and of which the concluding article appears in this issue, is being reprinted in pamphlet form in response to a demand for such a booklet.

A carefully prepared history of the metering art, the report contains four parts: I. Origins, covering invention and pioneering development before 1900, with particular attention to the men responsible (*EE, Sept. '41, p. 421–7*); II. Growth and Development, outlining progress in the art from 1900 to the present, in improved methods and adaptations to modern production trends (*EE, Oct. '41, p. 469–78*); III. Special Applications, showing how the basic energy-metering unit has been modified for use with three-wire and polyphase circuits and describing the development of demand meters (*EE, Nov. '41, p. 540-6*); and IV. Calibration and Installation of Watt-Hour Meters (*p. 581–6*). An appendix to the series (*p. 587–9*) lists sources of material, not only books and magazine articles, but museums and collections, and includes a tabulation of significant meter patents. Believed to be the first historical survey of this type on the subject of metering, the report not only has great value and significance for all those interested in meters, but also constitutes an important chapter in the yet-unwritten history of the electrical industry.

Copies of the pamphlet "Progress in the Art of Metering Electric Energy" may be obtained from the AIEE order department, 33 West 39th Street, New York, N. Y. Prices are 25 cents per copy to AIEE members; 50 cents per copy to nonmembers; special prices will be quoted on quantity orders.

District • • • •

District 7 Announces 1940 Prizes

The AIEE South West District (7) has announced District prize awards for student papers presented during the academic year ending June 30, 1940. Other District prizes for 1940 papers were announced in ELECTRICAL ENGINEERING, July 1941, page 351, and September 1941, page 428.

District 7

Prize for Branch paper was awarded to Robert P. Watson (Enrolled Student) for his paper "Electronic Visualization of Magnetic Fields," presented at the South West District Branch conference, April 19–20, 1940, Lubbock, Tex. Honorable mention for Branch paper was given to Leroy W. Evans and Raymond E. Glass (Enrolled Student) for their paper "The Study of the Accumulation of High-Potential Static Charges by Wind-Tunnel Method," and to Max H. Mesner for his paper "The Voltage Quadrupler," presented at the same Branch conference.

Prize for graduate student paper was awarded to Luther E. Johnson (A'41) for his paper "A Consideration of Some Possibilities for Electrical Engineering in Ordinary Land Surveying," also presented at the South West District Branch conference, April 19–20, 1940, Lubbock, Tex. Honorable mention for graduate student paper was given to LeRoy C. Tillotson (A'39) for his paper "An Analysis of the Single-Phase Full-Wave Gas Rectifier Loaded with a Choke Input Filter," presented at the same Branch conference.

Section • • • •

Leland Olds Addresses Joint Washington-Maryland Meeting

Reported as one of the most heavily attended AIEE Section meetings to be held in Washington, D. C., was the joint meeting of the Maryland and Washington Sections held November 17 in the auditorium of the Potomac Electric Power Company. Some 300 persons, about 100 of them from the Maryland Section, brought out "S.R.O." signs, according to reports. Some 160 of those attending also attended a dinner in honor of the speaker held in advance of the meeting.

Chairman Leland Olds of the Federal Power Commission, vice-chairman of the National Power Policy Committee, addressed the joint gathering on the subject "Power for National Defense." Mr. Olds discussed in some detail the present power situation, with special reference to the fundamental importance of adequate electric power to the whole national defense program. He discussed the relation of expected power demand to available power supply, and outlined the steps that are being taken to minimize any shortage in any area.

It seems probable that Chairman Olds discussed a good many of the points that will be treated in an article "Power System Development on a National Scale," prepared by Thomas R. Tate, director, National Defense Power Staff, Federal Power Commission, for the forthcoming January issue of ELECTRICAL ENGINEERING.

Sections Committee Urges Action on National Problems

The following letter, sent by the chairman of the AIEE Sections committee to all Institute vice-presidents, District secretaries, and chairmen of Sections, is here presented because it is believed by the Sections committee to be of interest and significance to the membership at large:

To All Vice-Presidents, District Secretaries, and Section Chairmen:

America must not lose its moorings.

Right now America is making a huge effort toward total National Defense.

Its first line of defense is the American home and all that it does or should represent.

Its second line of defense is its vast system of industries and supply of raw materials.

Its third line of defense is national unity.

Those represent preparations for war.

They have been in the process of formulation for years.

Now is the time to prepare for the repercussions of peace.

Emotions must be stabilized by some sound thinking.

Our national spiritual foundation must be reinforced.

Much of the old unrestricted enterprise is gone.

America must face realistically such restrictive regulation as may be needed and exert every influence in the conduct of business to prevent overregulation.

America has the greatest industrial plant in history. It has enormous funds. It has adequate man power and brains. These *must be utilized* to relieve the shock of peace.

Engineers have been held responsible for the recent economic upheaval.

Now the whole world has turned to them pleading for rescue from chaos.

Here is unparalleled opportunity calling for the right kind of leadership supported by teamwork.

America needs it more than at any time in its existence.

Let us as engineers be quick to seize this challenge.

Freedom of religion must be preserved.

Freedom of education must be preserved.

Freedom of speech must be preserved.

Freedom of the press must be preserved.

Freedom of enterprise consistent with social welfare must be preserved.

Freedom to choose and to change representation in government must be preserved.

Plants and employees must be kept busy producing new products and more products for more people at less cost.

The preservation of all of these freedoms is fundamental to the continuance of the American way of life.

The American way of life provides a large measure of individual opportunity, but it requires in return individual responsibility to society as a whole.

Attention has been directed to some of the major problems of the present and future by Charles E. Wilson (ELECTRICAL ENGINEERING, March 1941), by Howard Coonley (ELECTRICAL ENGINEERING, July 1941), by AIEE President D. C. Prince (*General Electric Review*, July 1941), and by many others.

Electrical engineers are among the recognized leaders in our nation.

Your Institute officers urge you to preserve and to strengthen that position of leadership.

There is capable leadership in every Institute Section. Put it to work. Give it your support.

Your Institute officers urge upon each Section:

1. That it will try to develop an increasing sense of professional conscientiousness and a measure of obligation to assume distinctive, constructive leadership in the problems of human relations, community interests, and public relations in the local area.

2. That it will assist in determining the readjustments that must be made, then *work with a will before it is too late*. In many instances members may have the opportunity to work with the local engineering council which, in turn, can co-operate with the local chamber of commerce and other civic bodies.

3. That it will undertake a program of vocational education, especially co-operating with the high schools and the colleges in which this new challenge to the engineering profession will be injected.

4. That it will make this broad effort objective number one by devoting an early meeting at which this next national job may be presented and discussed.

5. That it will appoint one or more of its members to direct this special effort and keep it moving.

6. That it will submit to the chairman of the Sections committee for distribution to all other Sections such materials and ideas as may assist in moving this program forward.

DO NOT WAIT—ACT NOW

M. S. COOVER
Chairman, Sections Committee

Sections Consider Peacetime Planning

Three Institute Sections, Cleveland, Philadelphia, and Niagara Frontier, are giving attention to the development of workable plans for the shift to peacetime production at the end of the present emergency, the Sections committee reports.

The Cleveland Section has set up a "social conditions committee," which held its first meeting October 22, 1941. The desirability of continuing research during the emergency, various aspects of taxation and labor, importance of presenting all sides of economic problems in schools and colleges, consideration of a possible national slogan to identify and stimulate the work of the engineering profession on current problems were among subjects discussed. The committee is considering the feasibility of forming itself into a seminar to meet every two weeks for serious study.

Members Urged To Contact Local Sections

The Institute's Washington Section has sent word to national headquarters urging members normally affiliated with other Sections but now finding themselves more or less temporarily situated in the Washington Section territory, to make their whereabouts known to officers of that Section. It is pointed out that this would enable the Section to circulate meeting notices and would afford opportunity for direct participation in local Section affairs. Members temporarily established in Washington are invited to correspond with F. W. Willcutt, secretary, care Potomac Electric Power Company.

Members temporarily resident in the territory of other Sections likewise may find it profitable to identify themselves with officers of the nearest local Section. A complete listing of Sections will be found in the recent September issue of ELECTRICAL ENGINEERING.

Arizona Section Members Travel

The AIEE Arizona Section, newly organized during 1941, held its first fall meeting at Prescott, Ariz., with 10 members and 14 visitors present. The total mileage traveled by those attending the meeting was reported to be 5,442 miles, with the longest individual round trips 700, 600, and 500 miles. Only two persons present had round trips of less than 64 miles.

The meeting voted formal acceptance to the bylaws previously given tentative approval. The program was concerned with "Use of Electricity in Copper Mining in Arizona."

Abstracts • • •

TECHNICAL PAPERS are previewed in this section as they become available in advance pamphlet form. Copies may be obtained by mail by remitting price indicated to the AIEE order department, 33 West 39th Street, New York, N. Y., or at five cents less per copy if purchased at AIEE headquarters or at AIEE convention or District-meeting registration desks.

The papers previewed in this issue will be presented at the AIEE Winter Convention, New York, N. Y., January 26–30, 1942.

Air Transportation

42-7—A D-C Telemeter or D-C Selsyn for Aircraft; *R. G. Jewell (A'30) and H. T. Faus (M'34). 15 cents by mail.* A toroidal resistance winding having three taps spaced 120 degrees and a rotatable brush assembly which supplies d-c electric energy at diametrically opposite points constitutes the transmitter. The indicator comprises a permanent-magnet rotor surrounded by a core of low-hysteresis magnetic material carrying three delta-connected coils spaced 120 degrees. The three taps on the transmitter are connected to the three common points of the indicator coils. A diametrical magnetic field is established in the indicator which causes the magnetic axis of the permanent-magnet rotor to come into alignment. The position of the indicator magnetic field is dependent upon the position of the transmitter brushes. The torque, accuracy, size, and weight characteristics make this telemeter particularly suitable for the remote indication of various aircraft functions.

Basic Sciences

42-27—Formulas for the Magnetic Field Strength Near a Cylindrical Coil; *Herbert B. Dwight (F'26). 25 cents by mail.* A group of formulas involving natural logarithms is derived, to give the axial and radial magnetic field intensity at small distances from a solenoid, in the absence of magnetic material. The radial thickness of the solenoid winding is taken care of by additional formulas. Since these and other series formulas are the result of integration from one end of the solenoid to the other, they occur as the difference of two quantities. It is shown in this paper that it is advantageous to give a physical meaning to these two quantities separately, so that, for instance, one may be computed by a long-coil formula and the other by a short-coil formula, if desirable. This greatly increases the range in which the flux density of solenoids under all conditions can be precisely and quickly calculated. In order to express the formulas in the form just described, expressions are derived for the magnetic field strength at points in the end plane of an infinitely long solenoid. By arranging the available series formulas in the manner described, a complete equipment is given for computing the magnetic field of a circular solenoid of any shape and at any point, including points within the cross section of the winding. Several numerical examples are included. A chart is given to assist in choosing the appropriate formulas for a given case.

Electric Welding

42-25—Resistance-Welding Transients; *E. E. Kimberly (M'41). 15 cents by mail.* Many articles published on the subject of resistance welding deal briefly and qualitatively with the importance of switching transients in their effect on the total heat produced in a short-time weld. This paper deals with the same phenomenon quantitatively. Oscillograms of current and power in the weld show that in the first few cycles after random (indiscriminate phase-angle) switching in repetitive welding the heat input to the weld may vary from weld to weld as much as 50 per cent from the optimum. As the number of cycles in the weld period increases, the heat error caused by transient decreases. If the weld period is greater than about one third second, the heat error may be ignored, and although the cost of accurate switching control may be justified because of line-voltage disturbance and because of

exploding or splashing in projection welding, it cannot be justified for accurate heat-control alone. The need for accurate phase-angle switching when the weld time is very short and when the metallurgy of the stock requires accurate temperature limits is clearly shown.

Electrical Machinery

42-1—Progress Report of D-C Testing of Generators in the Field; *E. R. Davis (A'41) and M. F. Leftwich (A'30). 15 cents by mail.* Considerable interest has been shown in field tests of generator insulation, particularly with mobile test apparatus. The development of a portable d-c apparatus with a range of 0–14,000 volts, capable of testing large hydro- and turbogenerators, is set forth in this paper. The initial charging and insulation leakage current at various temperatures is described by several curves. A few interesting tests, which indicate definite possibilities of high voltage d-c testing, are cited to illustrate its feasibility. The method of correlating the test results on individual generators derives from 2,368 periodic field tests made over a period of ten years with high d-c voltage is presented. The detection of latent generator insulation weaknesses without damage to core iron or adjacent coils with a mobile high-voltage d-c test apparatus has proved economical from a service and operating standpoint.

42-3—Equivalent Circuits for the Hunting of Electrical Machinery; *Gabriel Kron (A'30). 15 cents by mail.* A general method is given to establish equivalent circuits for the determination of the hunting characteristics, such as damping and synchronizing torques, of standard types of electrical machines. The method is illustrated by setting up steady-state and hunting equivalent circuits for the salient-pole synchronous machine having amortisseur windings and for the doubly fed single-phase Selsyn with unbalanced windings, special cases of which are the capacitor motor and the doubly fed polyphase motor. A companion paper "The Doubly Fed Machine" (42-4) contains a detailed study of the characteristics of one of the equivalent circuits as measured on the a-c network analyzer.

42-4—The Doubly Fed Machine; *C. Concordia (M'37), S. B. Crary (M'37) and Gabriel Kron (A'30). 15 cents by mail.* This paper presents a general analysis of the doubly fed machine (a synchronous machine with polyphase a-c excitation on both stator and rotor) and shows the characteristic curves of damping and synchronizing torques during hunting, as affected by the machine parameters. Equivalent circuits are presented which may be set up on an a-c network analyzer, so that these damping and synchronizing torques during hunting may be determined simply by direct measurement of watts and vars in the circuit. Equations for the transient short-circuit currents are also included.

Industrial Power Applications

42-19—A Static Voltage Regulator Insensitive to Load Power Factor; *Claude M. Summers (M'39) and T. T. Short. 15 cents by mail.* A new type of static voltage regulator, for those applications where performance is more important than efficiency, is described in this paper. It has the distinction of supplying a constant output voltage which is independent of load power factor. The regulator in its preferred form consists of two reactors and two capacitors. One reactor and one capacitor form a constant-current circuit and the other capacitor and reactor form a constant-voltage circuit, so that the regulator first converts a variable-voltage source to a constant current and then to constant potential. The regulator has many interesting characteristics such as inherent overload protection, and high speed of response, as well as close regulation for simultaneous variation in line voltage, load, and load power factor. Brief descriptions of the design procedure, operating characteristics, and some applications are given.

42-21—The Fundamentals of Industrial Distribution Systems; *D. L. Beeman (A'31) and R. H. Kaufmann (M'41). 25 cents by mail.* The intensive manufacturing activity accompanying the present defense program has stimulated interest in industrial electric-power distribution. The ultimate objective is one of effectively satisfying electric-power requirements with reasonable first cost consistent with a fair standard of safety and service reliability. This paper presents the fundamental aspects of industrial power distribution, with particular reference to low-voltage power supply to distributed electrical machinery and compares various basic system designs, including large concentrated substations and distributed load-center substations with radial and secondary network modifications, as to safety, service reliability, simplicity, etc., relative to estimated installed cost. The comparative analysis comprehends the complete electrical system between high-voltage supply bus and utilization terminal of low-voltage feeders. The ideal size of unit substation as influenced by operating voltage and load density is covered. Principles of system design here disclosed are applicable not only to new plant construction but to expansion or modernization of existing plants as well.

Instruments and Measurements

42-5—The Acceleration-Oscillogram Method of Motor-Torque Measurement; *C. R. Atkinson (A'31) and E. G. Downie (A'35). 15 cents by mail.* The need for an improved method of measuring starting torque of large induction-starting synchronous motors, as compared with the power input and dynamometer methods, has led to the use of the acceleration oscillogram. A low-ripple permanent-magnet-type d-c generator is driven by the motor, and traces a time-speed oscillogram, from which acceleration, and the torque producing it, may be calculated. Comparative torque tests, at full and reduced voltage, made by this and the other methods on the dynamometer-coupled motor, showed the definite advantage of the acceleration tests in combined convenience and accuracy. Interesting facts about synchronous-motor starting torques, not accurately shown by previous tests, have been brought to light. The acceleration or deceleration oscillogram is also applied to the measurement of torques or losses of very small high-speed motors by using other methods of rotation indication involving no loading of the motor.

42-15—Measurement of Maximum Demand; *P. M. Lincoln (F'12). 20 cents by mail.* This paper describes in detail the thermal storage method of measuring the maximum demand of a user of electric service. It makes a comparison between this method and the commonly used block-interval method. It points out that the block-interval method must necessarily be a discontinuous function of time and as such be subject to a possible error of 50 per cent —a possibility that can become a certainty at the option of the service user—while the thermal storage method, being a continuous function of time, can only indicate a single value for maximum demand no matter what may be the character of the load under measurement. Tests on thermal-storage demand meters are given in some detail.

Land Transportation

42-23—Progress in Design of Electrical Equipment for Large Diesel-Electric Locomotives; *Gerald F. Smith (A'13). 15 cents by mail.* During the last eight years, as the result of development of the Diesel engine, Diesel-electric locomotives have come into wide use for heavy switching, passenger, and freight service. There has also been a rapid development in the electrical equipment, going back about 15 years. For present high-speed passenger locomotives, electrical equipment is available with a weight between 20 and 21 pounds per engine horsepower, with continuous rated speed 33 per cent of maximum service speed of above 100 miles per hour and with sufficient maximum tractive effort to slip wheels at 33 per cent adhesion. For freight locomotives with double the number of motors per power plant, the weight per engine horsepower is between 30 and 31 pounds per engine horsepower, and the continuous rated speed 16 per cent of maximum rated speed.

Power Transmission and Distribution

42-2—Relative Value of Different Types of Overcurrent Protection for Distribution Circuits; *G. F. Lincks (A'37). 15 cents by mail.* According to Lord Kelvin, we have only a meager and unsatisfactory knowledge of a subject until it can be measured and expressed numerically. Actual service data on the benefit of branch protection and line sectionalizing with protective devices connected in series are not available. It would be very difficult to obtain such data on all types of protective devices in service at different points on any one distribution circuit. This has been determined by a mathematical study. The actual consumer minutes outage has been expressed as a percentage of the outage time caused by permanent faults alone when no sectionalizing or branch protection is used. The study covered a range of temporary

faults from 25 to 85 per cent of the total number of faults. All types of fuse cutouts and reclosing breaker arrangements at the substation, at sectionalizing points connected in series, and on varying-length branches are included in the study. This knowledge of the relative benefits of distribution overcurrent protective equipments and their applications should be of value in economical system planning.

42-10—Temperature and Electric Stress in Impregnated-Paper Insulation; *J. B. Whitehead* (*F'12*) *and W. H. MacWilliams* (*Enrolled Student*). *15 cents by mail.* This paper reports studies of the time rate of change of power factor and loss in thoroughly impregnated paper insulation, due to the separate and to the combined influences of high temperature and high stress. It is found that the rate of deterioration as measured by power factor is very much greater for combined temperature and stress than for either singly, and in fact much greater than that observed when the oil contains a large amount of oxygen. These effects are very pronounced at temperatures and pressures only slightly above those now reached in the operation of power cables. They indicate rapid chemical changes in the insulation and are attributed to a great increase in electrolytic dissociation in the oil. Tests of this character should provide a reliable method for study of the relative chemical stabilities of cable and capacitor saturants.

42-13—Multichannel Carrier-Current Facilities for a Power Line; *P. N. Sandstrom* (*A'25*) *and G. E. Foster* (*A'32*). *15 cents by mail.* A carrier-current system providing a relatively large number of channels is in service on a high-voltage power line. The facilities provide:

1. Transmission of signals both ways for the opening of the circuit breakers at the remote end by the operation of relays at the near end.
2. Two-way telephone service between any extension telephone at the remote generating station and any telephone connecting to the main telephone switchboard in the central office building.
3. Two-way telemetering (station generation one way, and system total generation the other way).
4. Transmission from the system operator's office to the station of automatically generated load-control signal used to increase or decrease automatically the station generation.
5. Two channels in each direction for future requirements.

This paper describes the methods employed to obtain these channels over a single power line, including the special precautions taken with the high-speed transferred trip signals to prevent faulty tripping of the line due to external disturbances that might generate carrier-current tripping pulses.

42-14—Shielding of Substations; *C. F. Wagner* (*F'40*), *G. D. McCann* (*A'38*), *and C. M. Lear. 15 cents by mail.* A previous paper by the authors considered the shielding afforded transmission lines by ground wires and presented a method for suitably simulating the mechanism of natural lightning for laboratory tests with models. This paper continues the investigation as applied to the shielding of substation structures. Recommendations are given for the location of overhead ground wires and vertical masts to provide adequate shielding to the protected object.

42-16—Lightning Investigation at High Altitudes in Colorado; *L. M. Robertson* (*M'38*), *W. W. Lewis* (*F'38*), *and C. M. Foust* (*M'31*). *25 cents by mail.* An investigation was begun in 1938 on the Shoshone-Denver 100-kv line to determine the probable lightning current at altitudes from 6,000 to 13,500 feet. The results show a decrease of stroke current with altitude, and by extrapolation the entire absence of lightning current at about 18,000 feet is indicated. Observations of temperatures at high altitudes indicate that at 18,000 feet the air temperature never exceeds 32 degrees Fahrenheit. The possible connection between the absence of lightning current and temperatures at or near freezing is discussed. The percentage of positive currents was comparatively high. The investigation was extended to the measurement of corona current at 5,280 and 13,500 feet, and in 1941 measurements were obtained in 51 storms at 13,500 feet. A comparison with similar measurements made at low altitude indicates about the same maximum potential gradient, but a much higher average gradient at the high altitude.

42-17—Field Investigations of Lightning Currents Discharged by Arresters on the American Gas and Electric Company System; *I. W. Gross* (*M'40*), *G. D. McCann* (*A'38*), *and Edward Beck* (*M'35*). *20 cents by mail.* For the past three years data have been collected on the wave shape of lightning currents discharged by arresters in stations of the Ohio Power Company and the Appalachian Electric Power Company with Fulchronographs, cathode-ray oscillographs, and magnetic surge-front recorders. Fulchronographs and magnetic surge-front recorders have been installed at five three-phase arrester banks. At two of these, cathode-ray oscillographs were also installed. Records have been obtained of 49 single-phase arrester discharges which yielded Fulchronograph records of 88 individual components, cathode-ray oscillographs of 9, and magnetic surge-front records of 18.

42-18—Lightning Investigation on 132-kv System of the American Gas and Electric Company; *I. W. Gross* (*M'40*) *and G. D. Lippert* (*A'38*). *25 cents by mail.* This paper presents and discusses field records of natural lightning currents recorded on the 132-kv transmission system of the American Gas and Electric Company during the past nine years, although most of the records have been obtained during the past four years. Magnitude and frequency data on lightning currents in transmission wires, ground wires, tower structures, counterpoises, and ground rods are given. There are also discussed records obtained by the wave-slope indicators on the rate of change of voltages appearing at the entrance to transmission stations, some of which at least are caused by lightning. These data are considered in connection with recorded line currents entering a station and coordinated with the rates of voltage rise, calculated line surge impedance, bus voltages, and lightning-arrester performance. Comparison of effectiveness of various lengths and designs of counterpoises and ground rods is given.

42-22—Impulse and 60-Cycle Characteristics of Driven Grounds—II; *P. L. Bellaschi* (*F'40*), *R. E. Armington* (*Enrolled Student*), *A. E. Snowden* (*Enrolled Student*). *30 cents by mail.* This paper extends the contribution of the first paper experimentally, theoretically, and from the application standpoint. Data are presented on 16 grounds ranging from 8 to 30 feet deep. Eleven are in clay soil, two in gravelly soil, one in sand, and two in a mixture of clay and stones. Sixty-cycle data and impulse data up to 15,500 amperes are given for the single grounds and for parallel combinations. Curves, tables, and typical cathode-ray oscillograms sum up the more pertinent findings. Methods have been developed for determining 60-cycle and impulse characteristics of single and parallel grounds. Curves calculated are in substantial agreement with the experimental results. The discharge-circuit inductance of a ground installation is dealt with and its significance is discussed.

Protective Devices

42-8—Performance of Ground-Relayed Distribution Circuits During Faults to Ground; *C. L. Gilkeson* (*M'34*), *P. A. Jeanne* (*M'30*), *and J. C. Davenport. 15 cents by mail.* In connection with studies by the Joint Subcommittee on Development and Research of the Edison Electric Institute and Bell Telephone System, of problems of protection where power and telephone circuits are on jointly used poles, extensive oscillographic observations were made of the performance of relaying systems and other equipment for clearing ground faults on power distribution circuits, chiefly on circuits above five kilovolts. Of the data obtained, those relating to feeders equipped with instantaneous ground relays and for immediate reclosure have been selected for presentation in this paper as being of considerable interest outside the specific study for which they were secured. Data are given as to the means by which faults were cleared, speed of initial interruption and of automatic reclosure, per cent of faults clear on first reclosure, fuse and relay coordination, fault characteristics, etc. Also limitations on ground relaying imposed by fuse and relay co-ordination, residual load currents and transients following feeder re-energization are discussed.

42-9—Field Tests and Performance of a High-Speed 138-Kv Air-Blast Circuit Breaker; *Philip Sporn* (*F'30*) *and H. E. Strang* (*M'39*). *15 cents by mail.* A 138-kv air-blast circuit breaker of novel design has recently been subjected to a series of field tests, up to values of short-circuit duty substantially in excess of its assigned rating of 1,500,000 kva. These tests included both normal interrupting duty and superspeed reclosing service when the breaker was called upon to interrupt, reclose in less than 20 cycles, and again interrupt the fault current. While still somewhat of an innovation in the high-voltage field, the air-blast circuit breaker undoubtedly has certain basic advantages. It is

believed that these tests are an important step forward in developing the possibilities of the air-blast breaker for high-voltage service and that they have brought the entire electric-power industry closer to the possibility of benefit from an application of this interrupting principle.

42-11—Current-Transformer Performance Based on Admittance-Vector Locus; *A. C. Schwager (M'31). 15 cents by mail.* In the past, current-transformer performance has been defined by ratio-error and phase-angle curves in which the abscissa represents primary or secondary current to a linear scale. Numerous curves were necessary for determining the errors for the multiplicity of secondary burdens. This paper shows that a more functional picture of current-transformer operation is obtained by replacing these curves by the admittance-vector locus of the secondary winding. The numerous ratio and phase-angle curves resulting from various secondary burdens and, in case of multiratio transformers, from different numbers of turns, revert to one single curve. Ratio error and phase angle for any burden at any power factor, turn ratio, and secondary current, can be scaled or read directly from a single chart containing the admittance-vector locus.

42-12—Field Tests on High-Capacity Station Circuit Breakers; *H. D. Braley (A'18). 15 cents by mail.* The development of high capacity air-blast breakers in the United States has taken place without the background of operating experience that has attended the use of oil circuit breakers and has, therefore, emphasized the need for testing this equipment at levels comparable with the assigned interrupting ratings. Although field short-circuit tests to verify circuit-breaker performance have been made on operating systems previously, they have been limited in most instances to moderate-duty levels or, in the larger interrupting ratings, to the testing of high-voltage apparatus. Staging severe short-circuit tests at 15 kv introduces operating problems of greater significance since it virtually requires the application of the fault to the generating-station bus. This paper describes such an undertaking and presents:

1. A résumé of the studies which indicated that it would be practicable to stage short-circuit tests ranging up to 2,000 megavolt-amperes directly on a particular generating-station bus.

2. A description of the physical plant equipment assembled for test purposes.

3. Operating experience during a series of 14 short-circuits ranging from 200 to over 1,500 megavolt-amperes at 14.5 kv.

42-20—Loss-of-Field Protection for Generators; *G. C. Crossman (A'30), H. F. Lindemuth (M'41), and R. L. Webb (M'35). 25 cents by mail.* The features of a new protective-relay scheme designed to protect a-c generators for severe reduction in field excitation are described. This scheme operates to remove the underexcited machine from the system upon occurrence of resultant undervoltage before loss of synchronism occurs. Calculation methods required to apply the scheme are covered, together with a sample problem to assist with such applications on any system. A need for loss-of-field protection has been found on the larger machines of a metropolitan operating company. The considerations involved when studying need for such protection are outlined, together with the complete description of machine behavior and records of actual tests to show that those behaviors can be determined with reasonable accuracy.

42-24—High-Speed Single-Pole Reclosing; *J. J. Trainor, J. E. Hobson (M'41), and H. N. Muller, Jr. (A'37). 20 cents by mail.* Recently the Public Service Company of Indiana, Inc., installed the first application of high-speed, single-pole reclosing in the United States. This application is on its single-circuit 132-kv line, extending from Lenore to Newcastle, which line forms part of an interconnection between the Public Service Company of Indiana and the Indiana section of the American Gas and Electric System. Calculations are included which show the comparative transient power limits with gang operation and single-pole operation for speeds of reclosing of 35 and 20 cycles on a 60-cycle basis. Comprehensive tests were conducted to check the single-pole relay and circuit breaker operation for both arcing and solid faults applied at various points on the transmission system. The test results are included in the paper. A general discussion comparing the use of gang operation and single-pole reclosing with other measures for improving transmission-line performance is included.

Personal • • •

D. C. Prince (A'16, F'26) manager, commercial engineering department, General Electric Company, Schenectady, N. Y., and president of the Institute, has been made vice-president in charge of application engineering, apparatus department. **W. R. G. Baker** (A'19, M'41) manager, radio and television department, Bridgeport, Conn., has been appointed vice-president of the radio and television department for the company. **H. A. Winne** (A'16, M'39), staff assistant to the vice-president in charge of engineering, Schenectady, has been appointed vice-president in charge of design engineering, apparatus department. A biographical sketch of Mr. Prince appeared in the March 1941 issue, page 138. Mr. Baker was born November 30, 1892, at Lockport, N. Y., and received the degrees of bachelor of science (1916) and mechanical engineer (1918) and an honorary degree of doctor of science (1935) from Union College. He has been with the General Electric Company since 1917, starting in the research laboratories. In 1924 he was given charge of design of all radio products, and in 1928 complete charge of development, design, and production in the radio field. In 1930 he became vice-president and general manager of the RCA Victor radio plant, Camden, N. J., but returned to General Electric Company in 1935 to become manager of the radio and television department at Bridgeport. Mr. Winne was born October 27, 1888, at Cherry Valley, N. Y., and received the degree of electrical engineer from Syracuse University in 1910. He joined the General Electric Company in 1910, working in the test department. In 1916 he became application engineer in the power and mining and industrial engineering departments, and in 1930 was put in charge of a section of the industrial engineering department. He became manager of sales, mining, and steel-mill section of the industrial department in 1936, and in 1937 was made staff assistant to the vice-president in charge of engineering.

H. L. Crumley (A'26, M'27) formerly general superintendent of operations, Virginia Public Service Company, Charlottesville, has been appointed operating vice-president for the company, with headquarters at Alexandria. **Ivan Buys** (A'24) chief electrical engineer, Illinois Iowa Power Company, Decatur, Ill., has been appointed general superintendent of operations. Mr. Crumley was born in Atlanta, Ga., June 30, 1900, and received the degree of bachelor of science in electrical engineering from the Georgia School of Technology in 1920. He entered the test course of the General Electric Company in 1920, and joined the Georgia Railway and Power Company, Atlanta, in 1921, serving first as tester, and later as assistant foreman of the test department and as protection engineer. He became relay engineer for the Metropolitan Edison Company and New Jersey Power and Light Company, Reading, Pa., in 1926, and was made assistant superintendent of operation in 1927, and chief system operator in 1932. In 1937 he joined the E. M. Gilbert Engineering Corporation as consulting electrical engineer, and went to the Virginia Public Service Company as general superintendent about a year later. Mr. Buys is a native (1896) of Rutherford, N. J., and received the degree of mechanical engineer from Cornell University in 1917. After two years in the United States Army Signal Corps, he joined the Duquesne Light Company, Pittsburgh, Pa., and became successively technical assistant to superintendent of overhead lines, assistant chief of construction, and chief of operation of transmission lines. He became superintendent of transmission for the Kansas Gas and Electric Company, Wichita, Kans., in 1923, and in 1930 transferred to the United Power and Light Corporation of Kansas, Abilene, as chief engineer and later division manager. He joined the Illinois-Iowa Power Company in 1936, as engineering assistant to the vice-president, and was made chief engineer about a year later.

H. P. Charlesworth (M'22, F'28) has retired as assistant chief engineer, American Telephone and Telegraph Company, New York, N. Y. Mr. Charlesworth was born April 7, 1882, at Haverhill, Mass., and graduated in electrical engineering from Massachusetts Institute of Technology. He entered the service of the American Telephone and Telegraph Company at Boston in 1905, and did research and development work in the engineering department. In 1907 he was transferred to New York, to enter the toll traffic department. From 1917 to 1919 he was assigned to problems in connection with the war-time emergency, and later in 1919 was made equipment and transmission engineer for the company. He was appointed plant engineer in 1920, and in

1928 was transferred to the Bell Laboratories as vice-president. He became assistant chief engineer of the American Telephone and Telegraph Company in 1933. Mr. Charlesworth was a manager of the Institute 1923–27, vice-president, 1930–32, and president, 1932–33. He also has been active on many Institute committees. **H. S. Osborne** (A'10, F'21) plant engineer, will carry on Mr. Charlesworth's duties, but will retain his present title of plant engineer. A biographical sketch of Mr. Osborne appeared in the January 1941 issue, page 44.

R. I. Parker (A'14, M'20) district manager, central-station department, General Electric Company, Chicago, Ill., has been appointed assistant district manager of the company's central district. Mr. Parker has been with the company since 1912, having entered the test course at Schenectady, N. Y., and later having been transferred to the lighting engineering department. He was sent to the Chicago district office in 1919, and was made assistant manager of apparatus sales in 1921. He became district manager of the central-station department in 1924. **S. W. Scarfe** (M'40) commercial engineer for the company at Los Angeles, Calif., has been made assistant manager of the Los Angeles central-station department. He joined the company's sales department at San Francisco, Calif., in 1924 transferred to the test department at Schenectady, and returned to San Francisco in 1926. He was made resident sales engineer at Fresno, Calif., in 1927, and at Sacramento, Calif., in 1932, and became assistant to the manager of the company at San Francisco in 1937, and commercial engineer in 1939.

F. C. Weiss (A'14, M'19) manager, engineering and construction department, Alabama Power Company, Birmingham, has been appointed a vice-president of the company. Mr. Weiss was born in Dallas, Tex., March 5, 1892, and received the degree of bachelor of science in electrical engineering from Massachusetts Institute of Technology in 1913. In 1911 he joined the Stone and Webster Corporation, doing construction work in Texas, Iowa, and Missouri, and in 1913 became inspector of transmission-line construction for the Alabama Power Company. He later became assistant to the operating manager, superintendent of line construction, superintendent of electrical construction, and superintendent of construction for the company. After serving as superintendent, construction manager, and vice-president of the Dixie Construction Company, Birmingham, and construction manager of Allied Engineers, Inc., Birmingham, he returned to the Alabama Power Company as manager of the engineering and construction department.

E. R. Moore (A'26, M'40) electrical system, Detroit (Mich.) Edison Company, has been appointed budget engineer for the company. **C. F. Ries** (A'19) supervisor of training, has been appointed assistant to superintendent of substations. He will also continue with his former duties. Mr. Moore is a native (1898) of Williamsport, Pa., and received the degree of bachelor of science in electrical engineering from Pennsylvania State College in 1920. He has been with the Detroit Edison Company since 1926, serving first as engineer in charge of design of extensions to d-c substations and system, and later as engineer in charge of the preparation and co-ordination of the electrical system budget and procurement of equipment. A native (1891) of Kenton, Ohio, Mr. Ries received the degree of electrical engineer from Ohio Northern University. He has been with the Detroit Edison Company since 1917, having served successively as tester, electrical engineer, and supervisor of training.

H. H. Barnes, Jr. (A'00, F'13) commercial vice-president, General Electric Company, New York, N. Y., has been appointed AIEE executive committee representative on the newly-formed Engineers' Defense Board, a working organization of engineers and technologists from the several national engineering societies which will deal with technical problems on shortages, substitutions, conservation, raw materials, production and reclamation resulting from the defense effort. The other AIEE representatives are: **Philip Sporn** (A'20, F'30) vice-president in charge of engineering, American Gas and Electric Service Corporation, New York, N. Y.; **C. A. Adams** (A'94, F'13) consulting engineer, Edward G. Budd Manufacturing Company, Philadelphia, Pa.; **C. B. Jolliffe** (M'34) engineer in charge, RCA frequency bureau, Radio Corporation of America, New York, N. Y.; and **R. L. Jones** (A'11, F'31) director of apparatus development, Bell Telephone Laboratories, Inc., New York, N. Y.

W. W. Broadbent (A'16) assistant superintendent, southern division, Narragansett Electric Company, Providence, R. I., has been appointed superintendent of the southern division operating department of the New England Power Association with headquarters at Providence. He received the degree of electrical engineer from Lehigh University in 1910, and after taking the apprentice shop course at the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., became construction inspector for the New York, Ontario, and Western Railroad at Mayfield, Pa. He subsequently served in the same capacity with J. N. Bastress and company, Scranton, Pa.; New England Engineering Company, in Virginia and Ohio; Shore Line Electric Railway Company, Norwich, Conn., and Narragansett Electric Company. He was later made assistant superintendent of production and then assistant superintendent of the southern division, for the company.

L. G. Woodford (M'31) assistance vice-president, American Telephone and Telegraph Company, New York, N. Y., has been appointed chief engineer for the company. Mr. Woodford was born August 10, 1888, at Waterloo, Iowa, and studied engineering at Iowa State College. He joined the Iowa Telephone Company in 1911 as engineering assistant, and became appraisal engineer in 1914. He became appraisal engineer for the Northwestern Group of Bell Telephone Companies in 1916, and was made engineer of costs and practices in 1921. During 1923–24 he engaged in special studies for the American Telephone and Telegraph Company, and in 1924 was made appraisal engineer at New York. He became plant extension engineer in 1933, operating results engineer in 1937, plant operation engineer in 1939, and assistant vice-president in 1940.

E. T. Williamson (A'22) electrical engineer, People's Power Company, Moline, Ill., has been elected vice-president in charge of operations. A native (1897) of Independence, Mo., Mr. Williamson received the degree of bachelor of science in electrical engineering from Kansas State Agricultural College in 1919. He entered the test department of the General Electric Company, Chicago, Ill., in 1919 and was transferred to the a-c engineering department in 1920, and later to the power and mining department. About 1922 he became distribution engineer for the United Light and Railways Company (later United Light and Power Company), Davenport, Iowa, and three years later joined the People's Power Company as engineer. He was made electrical engineer five years ago.

L. E. Johnson (A'41) instructor in electrical engineering, New Mexico State College, State College, N. M., has been awarded the District 7 prize for best graduate student paper presented during the academic year ending June, 1940, for his paper "A Consideration of Some Possibilities for Electrical Engineering in Ordinary Land Surveying." Mr. Johnson was born at Corpus Christi, Tex., July 26, 1910, and received the degrees of bachelor of science in electrical engineering (1935) and master of science in electrical engineering (1940) from Texas Agricultural and Mechanical College. From 1936 to 1939 he was observer for the Texaco Development Corporation, Los Angeles (Calif.) division, and he joined the faculty of Mexico State College in 1940.

R. H. Olson (A'21) New York, N. Y., district sales manager, Electric Machinery Manufacturing Company, Minneapolis, Minn., has been appointed eastern sales manager for the company. Mr. Olson joined the Electric Machinery Company in 1919, as a tester, and was later made erecting engineer. In 1920, he became a partner of the firm Pearson and Olson, service engineers, which was established as the handling service department of the Electric Machinery Company. He returned to the company about 1924 as district sales manager at St. Louis, Mo., and was later also district sales manager at Minneapolis for a short time before being transferred to New York about 1929.

W. L. Cisler (M'35) assistant chief engineer, electrical engineering department, Public Service Electric and Gas Company, Newark, N. J., has been appointed to the staff of the power co-ordinator, Office of Production Management, Washington, D. C. He has been with the Public Service company since 1922 and is currently chairman of the AIEE committee on power generation. Also appointed to the staff of the power co-ordinator are: **F. H. King** (A'31, M'40) superintendent since 1937 of the

electric light department, City of Burlington, Vermont; and K. W. Miller (A'23, M'29) secretary, director of research, Utilities Research Commission, Chicago, Ill.

L. C. Tillotson (A'39) graduate assistant, electrical-engineering department, University of Missouri, Columbia, has been given honorable mention in the District 7 award for best graduate student paper presented during the year ending June 1940, for his paper "An Analysis of the Single-Phase Full-Wave Gas Rectifier Loaded with a Choke Input Filter." Mr. Tillotson received the degree of bachelor of science in electrical engineering from the University of Idaho in 1938, and worked for a year as electrician for the Bunker Hill and Sullivan Mining Company, Kellogg, Idaho, before going to the University of Missouri as assistant. He is a member of Sigma Xi.

G. S. Whitlow (A'29, M'39) application engineer, St. Louis (Mo.) office, General Electric Company, has joined the Union Electric Company of Missouri, St. Louis, as electrical engineer. Mr. Whitlow entered the General Electric Company in 1924, as a student in the test courses at Schenectady, N. Y., and Pittsfield, Mass., and in 1925 was made head of automatic switchgear testing at the Schenectady and Philadelphia (Pa.) plants of the company. In 1927 he supervised installation of three automatic substations in Havana, Cuba. He was made application engineer at St. Louis in 1928.

E. G. Thoms (A'28) inductive co-ordination engineer, Indiana Bell Telephone Company, Indianapolis, has been made plant extension engineer. Mr. Thoms joined the company in 1923, serving first in the department of exchange plant engineering. During 1926 he was transmission and distribution engineer for the Indianapolis-Cincinnati Traction Company, Indianapolis. He returned to the Indiana Bell Telephone Company in December 1926, as assistant foreign wire relations engineer, and was made inductive co-ordination engineer about 1930.

C. A. Terry (A'18, F'38) manager of power supply, Central New York Power Corporation, Syracuse, N. Y., has been appointed operating manager. J. L. Welch (A'27) general superintendent of distribution, has been appointed general superintendent of the Syracuse-Oswego division, with headquarters at Syracuse. Mr Terry has been with the Central New York Power Corporation as manager of power supply since about 1938. Mr. Welch has been with the company since about 1937, and was made general superintendent of distribution two years ago.

A. F. Brooks (A'24) formerly vice-president and general manager, Southern New England Telephone Company, New Haven, Conn., has been elected president of the company. A native (1890) of Meriden, Conn., Mr. Brooks received the degree of bachelor of philosophy from Yale University in 1911, and soon afterwards joined the Southern New England Telephone Company. He held various positions before being appointed cost and appraisal engineer, and was later made chief engineer. He was appointed vice-president and general manager of the company about 1930.

R. G. Edsall (A'23) electrical engineer-draftsman, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., has been appointed works electrical engineer in the factory service division of the company. Born at Atlantic City, N. J., June 17, 1901, he received the degree of bachelor of science in electrical engineering from Carnegie Institute of Technology in 1935. He has been with the Westinghouse company since 1919, serving successively as electrical apprentice, foreman of the test floor, and draftsman in the works engineering department.

Mildred A. Preen (A'39) junior partner, E. L. and A. G. Preen, contractors, Lebanon, N. J., has been elected representative to the New Jersey State Legislature from Hunterdon County. Miss Preen was born June 13, 1918, at Newark, N. J., and received the degrees of bachelor of science in electrical engineering from Newark College of Engineering in 1938 and master of arts from Columbia University in 1939. She also has completed the first and secondary pilot training courses of the Civil Aeronautics Authority.

R. E. Glass (Enrolled Student) Chicago, Ill., has received honorable mention in the District 7 award for best Branch paper presented during the academic year ending June 1940, for a paper on "The Study of the Accumulation of High-Potential Static Charges by Wind-Tunnel Method," of which he is joint author with L. W. Evans. Born at Hartley, Tex., January 6, 1917, Mr. Glass received the degrees of bachelor of science, Texas Technological College, 1940, and master of science, Illinois Institute of Technology, 1941.

F. L. Arland (A'22, M'30) engineer of special studies, New York (N. Y.) Telephone Company, has retired. Mr. Arland was born January 29, 1880, at Hammondsport, N. Y. He joined the New York Telephone Company in 1911 as division equipment engineer at Albany, and in 1920 became engineering assistant in the engineering department at New York. He later was made assistant engineer and engineer of the department. He was appointed engineer of special studies in the executive department in 1928.

C. A. Butcher (M'22) eastern district service manager, Westinghouse Electric and Manufacturing Company, Newark, N. J., has been made assistant manager of the district manufacturing and repair department with headquarters at East Pittsburgh, Pa. He has been with the Westinghouse company in various cities since 1917, and was made northeastern district engineering manager at New York, N. Y., in 1929, and eastern district service manager in 1936.

W. C. Lenhardt (A'37) electrical engineer, Cornwall ore division, Bethlehem Steel Company, Cornwall, Pa., has been made electrical superintendent for the division. A native (1914) of Syracuse, N. Y., he received the degree of bachelor of science in electrical engineering from Syracuse University in 1936. He joined the Bethlehem company in 1936 as student engineer, and was made electrical engineer about two years later.

C. W. Gustafson (A'25, M'29) chief engineer, Mill Mutual Fire Prevention Bureau, Chicago, Ill., has become sales engineer for I. A. Bennett and Company, Chicago, midwestern agents for the National Electric Products Corporation of Pittsburgh, Pa. He graduated in electrical engineering from Michigan State College in 1922, and immediately joined the Mutual Fire Prevention Bureau as engineer, being made chief engineer in 1926.

H. W. Leitch (A'98, M'13) consultant on special assignments, Consolidated Edison Company of New York, Inc., New York, has retired from active service with the company. He retired from the position of vice-president in charge of electrical operation at the end of 1940, but had remained with the company in a consulting capacity. A biographical sketch of Mr. Leitch appeared in the January 1941 issue, page 43.

F. L. Ball (A'22, M'27) regional executive, New England Power Association has been made president of the Malden (Mass.) Electric Company, and will also continue as an officer of various operating companies of the Association north and northeast of Boston. He has been an executive of the Association since about 1936, having served prior to that as an executive of several New England utility companies.

G. J. Thaler (Enrolled Student) graduate student, Johns Hopkins University, Baltimore, Md., has been awarded the District 2 prize for the best Branch paper presented during the academic year ending June 1940, for his paper "Characteristics of Fluorescent Lamps." Mr. Thaler was born in Baltimore, Md., March 15, 1918, and received the degree of bachelor of engineering from Johns Hopkins University in 1940.

R. P. Watson (Enrolled Student) Dallas Tex., has been awarded the District 7 prize for best Branch paper presented during the academic year ending June 1940, for his paper "Electronic Visualization of Magnetic Fields." Born September 5, 1917, at Dallas, Tex., Mr. Watson received the degree of bachelor of science from Southern Methodist University in 1941.

R. H. Barclay (A'14, F'28) formerly regional director, Federal Power Commission, New York, N. Y., has joined the J. G. White Engineering Corporation, New York, N. Y., as electrical engineer in charge of the division of electrical engineering. A biographical sketch of Mr. Barclay appeared in the September 1941 issue, page 449.

S. A. Moss (A'30) district plant manager, Chesapeake and Potomac Telephone Company, Washington, D. C., has been appointed general plant supervisor. He has been with the Chesapeake and Potomac company since 1924, and was made district plant manager about 1939.

H. L. Bradley (A'15) vice-president and treasurer, Allen-Bradley Company, Milwaukee, Wis., has been elected executive vice-president of the company. He has been with the company for many years, having served as vice-president and treasurer since about 1919.

O. E. Buckley (M'19, F'29) president, Bell Telephone Laboratories, New York, N. Y., has been elected an associate of the Roscoe B. Jackson Memorial Laboratory, Bar Harbor, Me. A biographical sketch of Dr. Buckley appeared in the October 1941 issue, page 506.

T. J. Killian (A'35) technical director, Barkon-Frink-Sterling Corporation, Long Island City, N. Y., has been commissioned lieutenant, senior grade, in the United States Naval Reserve Service. He has joined a special class of physicists at Massachusetts Institute of Technology, Cambridge.

H. L. Logan (A'19, M'28) managing engineer, Controlens division, Holophane Company, Inc., New York, N. Y., has been appointed as a consultant to the Industrial Visual Commission of the Public Health Bureau of the American Optometric Association.

J. G. Strang (A'40) construction engineer, National Broadcasting Company, New York, N. Y., has been put in charge of supervising construction on the new San Francisco (Calif.) Building of the company. He has been with the company since 1927.

I. B. Tilyou (A'38) electrical engineer, Copper Wire Engineering Association of Washington, D. C., Upper Darby, Pa., has joined the consulting engineering staff of the Chase Brass and Copper Company, Inc., Waterbury, Conn.

C. C. Knipmeyer (A'10, M'35) head, electrical engineering department, Rose Polytechnic Institute, Terre Haute, Ind., has been elected president of the National Council of State Boards of Engineering Examiners for 1941–42.

R. W. Beck (M'37) manager, Public Utility District 1, Grays Harbor County, Aberdeen, Wash., has resigned that position; **W. S. Hill** (A'13, M'20) general superintendent of production and construction for the district, has been appointed acting manager.

Robert Paxton (A'26, M'40) assistant to the manager, General Electric Company, Philadelphia, Pa., has been appointed manager of the Philadelphia Works of the company. A biographical sketch of Mr. Paxton appeared in the January 1941 issue, page 44.

C. E. Stephens (M'22) vice-president of the Westinghouse Electric and Manufacturing Company, has been appointed chairman of the electrical committee of the United States Committee for the Care of European Children, New York, N. Y.

R. M. Triest (A'34) manager, educational department, John Wiley and Sons, Inc., New York, N. Y., has been elected head of the editorial department and secretary of the company.

C. I. Maust (A'36) assistant engineer, Public Service Electric and Gas Company, Newark, N. J., has become assistant engineer for Ebasco Services, Inc., New York, N. Y.

C. H. Sharp (A'02, F'12) consulting engineer, White Plains, N. Y., has been awarded an honorary degree of doctor of science by Hamilton College.

Obituary • • •

Frederick F. Elliott (A'19) borough electrical engineer, Woolwich Borough Council, Woolwich, London, England, died May 8, 1941. Mr. Elliott was born February 15, 1892, at Brixton, London, England, and studied electrical engineering at the City and Guilds of London Technical College. During 1912 he was assistant engineer for the Thorpe Meter Syndicate, Ltd., London, and later became charge engineer for the City and South London Railway power station, London. He joined the British Insulated and Helsby Cables, Ltd., Prescot, Lancashire, in 1914, as electrical engineer, and in 1915 became charge engineer for the County of London Electrical Supply Company, Ltd., London. He became station engineer for the Woolwich Borough Council about 1920, and later was made successively electrical engineer in the electricity department, and borough electrical engineer. He was a member of the Institution of Electrical Engineers.

G. S. Lawler (A'11, M'13) chief electrical engineer, Associated Factory Mutual Fire Insurance Companies, Boston, Mass., died October 31, 1941. Born in Boston, Mass., in 1874, Mr. Lawler received the degree of bachelor of science from the Massachusetts Institute of Technology in 1897. From 1897 to 1899 he was electrician for the Halpin Dirigible Torpedo Company. In 1899 he enrolled in the test course of the General Electric Company, and shortly afterward joined the Boston Elevated Railway Company, serving until 1905 in various capacities and finally as superintendent of power distribution. After a brief period with the Brooklyn (N. Y.) Rapid Transit Company, as assistant superintendent of the Williamsburg Power Station, he became electrical inspector for the Associated Factory Mutual Fire Insurance Companies in 1906. He was later made electrical engineer, and became chief electrical engineer about 1918. He had participated in drafting every revision of the national electrical code since 1907.

Willard Ashley Stockbridge (A'11) foreman of power plants, Pennsylvania Railroad Company, Philadelphia, died August 20, 1941. Mr. Stockbridge was born March 31, 1885 at Fort Wayne, Ind., and graduated in electrical engineering from Purdue University in 1910. He joined the Pennsylvania Company, Fort Wayne, in 1910, working first in the photometric division of the company, and later doing tests on power plants and distribution. About 1916 he was employed in the office of the general superintendent of motive power, Pennsylvania Lines West, Pittsburgh, Pa., and five years later became power plant foreman for the Canton (Ohio) Shops of the Pennsylvania Railroad. He was later transferred to the West Philadelphia Shops of the railroad as power plant foreman, and became foreman of power plants at Philadelphia about 1930.

Elmer F. Anderson (A'35) electrical engineer, Portland (Ore.) General Electric Company, died October 4, 1941. Mr. Anderson was born September 3, 1896, at Portland, Ore., and received the degree of bachelor of science in electrical engineering from Oregon State College in 1925. From 1925 to 1927 he was switchboard wireman for the Portland General Electric Company, and in 1927 enrolled in the test course of the General Electric Company at Schenectady, N. Y. He returned to the Portland General Electric Company in 1928, entering the valuation department. He was transferred to the testing department in 1929, and in 1934 was made assistant engineer for the company. He later became electrical engineer.

Warren W. Daugherty (A'37) electrical superintendent, Cornwall ore division, Bethlehem Steel Corporation, Cornwall, Pa., died August 12, 1941. Mr. Daugherty was born in Crisfield, Md., November 11, 1879. From 1905 to 1916 he was general foreman for the Atlantic City and Shore Railroad Company, Philadelphia, Pa., in charge of construction and maintenance work on electric railroad line and car equipment. He joined the Cornwall ore division of the Bethlehem Steel Corporation in 1916, as chief electrician, and became electrical superintendent about 1937.

Membership • •

Recommended for Transfer

The board of examiners, at its meeting on November 27, 1941, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Flanders, N. M., dean of faculty and head of department of engineering tests, Bliss Electrical School, Takoma Park, D. C.
Woodford, L. G., chief engineer, American Telephone and Telegraph Company, New York, N. Y.

2 to grade of Fellow

To Grade of Member

Anderson, H. W., professor of electrical engineering, Iowa State College, Ames.
Anthony, B. M., assistant electrical engineer, Tennessee Valley Authority, Tupelo, Miss.
Blake, J. W., assistant superintendent of generation, Oklahoma Gas and Electric Company, Oklahoma City, Okla.
Currie, J. A., director and managing electrical engineer, C. A. Sothers, Ltd., Birmingham, England.
Priaby, E. F., assistant superintendent of production, Virginia Electric and Power Company, Petersburg, Va.
Leonard, M. G. electrical engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Hamlin, B. W., professor of electrical engineering, University of Texas, Austin, Texas.
Lewis, W. P., electrical cable engineer, American Steel and Wire Company, Worcester, Mass.
Manning, M. L., research engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Marburger, T. E., engineer, Consolidated Gas Electric Light and Power Company, Baltimore, Md.
Pearson, D. S., professor of electrical engineering, Ohio Northern University, Ada, Ohio.

Peterson, M. M., laboratory engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Sawyer, J. S., division electrical engineer, Central Ohio Light and Power Company, Findlay, Ohio.

Shelton, S. P., associate laboratory engineer, Bonneville Power Administration, Portland, Ore.

Shuster, J. D., electrical engineer, Bethlehem Steel Company, Quincy, Mass.

Somers, R. M., assistant chief engineer, T. A. Edison, Inc., West Orange, N. J.

Walz, J. O., engineering manager, Westinghouse Electric and Manufacturing Company, Lima, Ohio.

White, W. C., dean of engineering, Northeastern University, Boston, Mass.

Wilson, G., designing engineer, General Electric Company, Oakland, Calif.

19 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before December 31, 1941, or February 28, 1942 if the applicant resides outside of the United States or Canada.

United States and Canada

1. North Eastern

Cerwin, F. J., Central New York Power Corporation, Syracuse, N. Y.

Hermann, G. P., General Electric Company, Schenectady, N. Y.

Lindstrom, E., Line Material Company, Oneida, N. Y.

MacMillan, D. G., American Steel and Wire Company, Worcester, Mass.

Ray, J. H., American Steel and Wire Company, Worcester, Mass.

Ray, J. W., American District Telegraph Company, Inc., Boston, Mass.

Shickel, J. B., 208 Syracuse Building, Syracuse, N.Y.

Silver, C. W., General Electric Company, Schenectady, N.Y.

Wahlstrom, E. O., American Steel and Wire Company, Worcester, Mass.

Warchol, M. F., Jackson and Moreland, Boston, Mass.

Wiest, H. G., Jr. (Member), General Electric Company, Lynn, Mass.

2. Middle Eastern

Altar, W., Case School of Applied Science, Cleveland, Ohio.

Ashton, J. O. (Member), Carnegie Illinois Steel Corporation, Pittsburgh, Pa.

Baker, B. P., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Belinich, J. J., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Borub, W. E., General Electric Company, Toledo, Ohio.

Buckley, F.S., United States Navy, Philadelphia, Pa.

Clouse, W. W. (Associate re-election), Consolidated Gas and Electric Company of Baltimore, Baltimore, Md.

Ferlazzo, G., National Bureau of Standards, Washington, D. C.

Fultz, J. M., Jr., Bell Telephone Company of Pennsylvania, Philadelphia, Pa.

Gillilan, W. C., United States Navy Yard, Philadelphia, Pa.

Gross, K. K., Leeds and Northrup Company, Philadelphia, Pa.

Halpeny, O. M., United States Engineering Department, Cincinnati, Ohio.

Hamner, S. G., Jr., United States Navy, Baltimore, Md.

Harris, P. E., National Bureau of Standards, Washington, D. C.

Hey, J. A., Rural Electrification Administration, Washington, D. C.

Hill, D. A., Alliance Public Service Company and Ohio Public Service Company, Cleveland, Ohio.

Horischer, P. E., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Hyde, E. L., Bethlehem-Fairfield Shipyard, Incorporated, Baltimore-Fairfield, Md.

Johnson, C. H., Sun Oil Company, Toledo, Ohio

King, J. A., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

LeBianc, A. A., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Mancini, P. A., Rural Electrification Administration, Washington, D. C.

Mason, L. ., Consolidated Gas, Electric, Light and Power Company, Baltimore, Md.

Maxim, G. E. (Member), Picker X-Ray Corporation, Inc., Cleveland, Ohio.

McKeithan, W. L., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Moody, W. R., National Radio Institute, Washington, D. C.

Ormston, J. J., Jr., Westinghouse Electric and Manufacturing Company, Sharon, Pa.

Phillips, F., Elyria Foundry, Elyria, Ohio.

Phillips, W. B., Leeds and Northrup Company, Philadelphia, Pa.

Ray, B. M., University of Pittsburgh, Pittsburgh, Pa.

Russell, B. H. (Associate re-election), B. F. Goodrich Company, Akron, Ohio

Smith, H. L., Goodyear Tire and Rubber Company, Akron, Ohio.

Voelker, W. D., Leeds and Northrup Company, Philadelphia, Pa.

Wiesner, F. C. (Member), Cramp Shipbuilding Corporation, Philadelphia, Pa.

3. New York City

Dyson, G. W., Consolidated Edison Company of New York, Inc., New York, N. Y.

Humer, R. H., New York Telephone Company, Brooklyn, N. Y.

Meyers, S. T., Bell Telephone Laboratories, Incorporated, New York, N. Y.

Moynihan, V. A., Gibbs and Cox, Incorporated, New York, N. Y.

Smith, W. S., Metropolitan Device Corporation, Brooklyn, N. Y.

Sterner, E. H. (Member), Telefonaktiebolaget L. M. Ericsson, New York, N. Y.

Winans, B., New York State Electric and Gas Corporation, Brewster, N. Y.

4. Southern

Andrews, L. M., United States Navy Yard, Charleston, S. C.

Angelo, E. J., Jr., Tulane University, New Orleans, La.

Brubaker, L. H., United States Navy Yard, Charleston, S. C.

Daniels, F. A., Alabama Power Company, Birmingham, Ala.

Gilbreath, J. H., Tennessee Valley Authority, Chattanooga, Tenn.

Guthrie, R. J., Byrne Organization, Old Army Base, Norfolk, Va.

Long, K. H., United States Navy Yard, Charleston, S. C.

Richardson, O. (Member), Southern States Equipment Corporation, Birmingham, Ala.

Shortley, W. M., Southern Bell Telephone and Telegraph Company, Atlanta, Ga.

Stratton, W. L., Armature Winding Company, Charlotte, N. C.

Sweetling, C., United States Navy Yard, Charleston, S. C.

Taylor, E. R., City of Jacksonville, Jacksonville, Fla.

5. Great Lakes

Baird, M. N., General Electric Company, Fort Wayne, Ind.

Belt, D. F., Bendix Products, South Bend, Ind.

Braymer, D. T., Electrical World, Chicago, Ill.

Burian, K., Electrical Engineers Equipment Company, Melrose Park, Ill.

Greene, E. M. (Associate re-election), Albert Kahn, Incorporated, Detroit, Mich.

Heise, E. B. (Member), Northern Indiana Public Service Company, Michigan City, Ind.

Hill, F. E., Fisher Body Corporation, Detroit, Mich.

Juhnke, P. B., Jr., Line Material Company, Milwaukee, Wis.

Killian, S. ., (Associate re-election), Delta-Star Electric Company, Chicago, Ill.

Lawrence, L. E., Allen Bradley Company, Milwaukee, Wis.

Moncher, F. L., Fisher Body Corporation, Detroit, Mich.

Sarafian, K., Fisher Body Corporation, Detroit, Mich.

Siegel, R. C. (Member), Wisconsin Telephone Company, Milwaukee, Wis.

Svec, V., Harnischfeger Corporation, Milwaukee, Wis.

Warnock, E. W., Consumers Power Company, Adrian, Mich.

6. North Central

Becker, S., Hathaway Instrument Company, Denver, Colo.

Dieringer, J. ., Central Nebraska Public Power and Irrigation District, Hastings, Neb.

7. South West

Carothers, B. M., Union Electric Company of Missouri, St. Louis, Mo.

Hansen, E. L., United States Bureau of Reclamation, Elephant Butte, N. Mex.

Maguire, J. C., University of Texas, Austin, Tex.

Milner, M. S., Ford, Bacon and Davis, Inc., Little Rock, Ark.

Smoll, A. B., General Electric Company, Wichita, Kan.

Tuma, G., University of Oklahoma, Norman, Okla.

Uhr, I. A. (Member), General Electric Company, San Antonio, Tex.

Zeiders, M. ., Southwestern Bell Telephone Company, Oklahoma City, Okla.

8. Pacific

Horton, T. H., Bethlehem Steel Company, San Francisco, Calif.

Larson, P. F., Vega Airplane Company, Burbank, Calif.

O'Hara, P. L., Arizona Edison Company, Incorporated, Gila Bend, Ariz.

Pier, E. H., Douglas Aircraft Company, Incorporated, Santa Monica, Calif.

Ritter, A. L. (Associate re-election), Federal Communications Commission, San Diego, Calif.

Sargeant, G. H., Jr., Employers Liability Assurance Corporation, Limited, San Francisco, Calif.

Thompson, R. J., Trumbull Electric Manufacturing Company, Los Angeles, Calif.

9. North West

Brown, H. R. (Member), Boeing Aircraft Company, Seattle, Wash.

Drewett, G. A. (Member), Northwestern Electric Company, Vancouver, Wash.

Goldberg, M. O., Mountain States Telephone and Telegraph Company, Helena, Mont.

Mayer, R. H., Civil Aeronautics Administration, Anchorage, Alaska.

McGuire, M. H., City Water and Light Department, McMinnville, Ore.

Nystrom, H. R., Washington Water Power Company, Spokane, Wash.

10. Canada

Baxter, S. C., Burrard Dry Dock Company, Ltd., N. Vancouver, B. C.

Briggs, H. L. (Member), Hydro Electric System, Winnipeg, Man.

Faucher, W. (Member), Canadian Light and Power Company, St. Timothee, Beauharnois County, Que.

Lake, J., Burrard Dry Dock Company, Limited, North Vancouver, B. C.

Moss, A. S., Hydro Electric Power Commission, Toronto, Ont.

Rapsey, E. H., Square D Company Canada Limited, Toronto, Ont.

Sanger, J. S. (Member), Hydro Electric System, Winnipeg, Man.

Watson, C. R., Britannia Mining and Smelting Company, Britannia Beach, B. C.

Total, United States and Canada, 110

Elsewhere

Altmann, A. H. (Member), Standard-Waygood Limited, Sydney, N. S. W., Australia.

Anderson, G. A., Canterbury University College, Christchurch, New Zealand.

Brown, D. E. T. (Member), The Surat Electricity Company, Limited, Surat, India.

de la Torre, A. L., Westinghouse Electric International, Mexico, D. F.

Driscoll, W. H. (Member), Anglo-Ecuadorian Oilfields Limited, Casilla 410, Guayaquil, Ecuador.

Escuden, M. M., Westinghouse Electric International, Mexico, D. F.

Graeter, G. E. (Member), care of Contractors, Pacific Naval Air Bases, Midway Islands.

Nava, F. A., Westinghouse Electric International, Mexico, D. F.

Rao, S. K., Tata Oil Mills Company, Ltd., Tatapuram Post, Southern India.

Roldan, D. G., National Economy Bureau, Mexico, D. F.

Total, elsewhere, 10

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the addresses as they now appear on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Accioly, Pompeu Barbosa, Caixa Postal 571, Rio de Janeiro, Brazil, S. A.

Anderson, Axel W., Jr., 647 W. Sheridan Road, Chicago, Ill.

Andreasen, Ingwald A., 230—75th St., Brooklyn, N. Y.

Browning, Robert Lee, Jr., c/o Continental Oil Co., Conroe, Texas.

Butler, N. O., Route 1, Moore, Okla.

Butler, Oliver D., 1355 E. 47th Place, Chicago, Ill.

Cohen, LeRoy Daniel, 770 Meridian St., Florence, Ala.

Daily, Charles S., Jr., 1723 Eye St., N. W., Washington, D. C.

Dennis, Roman, Jr., 360 Amherst St., Buffalo, N. Y.

Direly, William L., c/o Ford Hotel, Buffalo, N. Y.

Farmer, Lee Linzey, Balboa Heights, C. Z.

Gould, John P., 2017 S. 59th Court, Cicero, Ill.

Hickey, Frank W., Jr., 750 Taylor St., San Francisco, Calif.

Hurd, Clinton T., Box 178, Seattle, Wash.

Lofstrand, A. L., Box 5043, Quarry Heights, C. Z.

Roberts, C. F., Jr., Houston Lighting & Power Co., Engg. Dept., Box 1700, Houston, Texas.

Romero, Robert F., 3200—13th St., N. W., Washington, D. C.

Schwarz, Donald William, 115 Lincoln Ave., Endicott, N. Y.

Smith, Clement R., 816 Leland Ave., South Bend, Ind.

Swan, Harry C., 586 Shoop Ave., Dayton, Ohio.

Thompson, Haddon, Storden, Minn.

Whitecarver, Robert S., 400 Center St., Wilkinsburg, Pa.

Wood, Frank Preuit, Dallas Power and Light Co., Dallas, Texas.

23 Addresses Wanted

Of Current Interest

Relation of ECPD to Professional Societies Discussed

Speaking at the recent annual dinner of the Engineers' Council for Professional Development, AIEE Representative J. F. Fairman considered his own experience and in that light proffered some pertinent suggestions as to the respective responsibilities of Council, the participating organizations, and the representatives of the latter. The essential substance of Mr. Fairman's address is contained in the following report.

IN considering possible inferences to be drawn from the word "relation", and the sequence of mention of the things related I followed the advice I so frequently give my children—go to the dictionary. One of the definitions I found is "the state of being mutually or reciprocally interested, as in social or business matters." This defines for me the "relation" between Council and the participating bodies. To this I would add one other shade of meaning—that implied in kinship, as father to son; or in the relationship of master to servant.

Our charter bears out this idea when it defines ECPD as a conference of engineering bodies organized to do a definite job—to enhance the professional status of the engineer. The text of the charter dealing with our objectives and program further confirms and amplifies this relationship, but in my opinion the argument is clinched by the phraseology of paragraph 4, defining the method of operation, which states "ECPD shall from time to time recommend to the governing boards of the participating bodies procedures considered to be of value or significance in promoting the general objective set forth in paragraph 2 and shall administer such procedures as shall have been approved by those boards." In other words, ECPD is the servant. It is definitely neither a superior body nor an all-powerful co-ordinating agency. It is the servant, to suggest; not the master, to command.

If I may modify the metaphor, ECPD is like unto a beautiful mansion, built by the family of professional societies with a great deal of enthusiasm for the broad outlook on common problems afforded by the site, but visited only occasionally by its masters, because of the pressure of business and other interests located elsewhere. The owners have left the place in charge of a large staff of their own selection. Once a year the servants send their masters a sort of New Year's greeting to reassure them that the house is in order in case they should wish to use it. The greeting is politely acknowledged and that is the end of it. The present major-domo, being a very conscientious man, was distressed not a little by the lack of interest shown by the owners, so he addressed a special message* to them, calling their attention to the fact that the staff desired to be of greater service. This was so extraordinary it commanded more than usual attention, but when the owners found it was not a strike threat, they relaxed again.

The apparent indifference of our masters has lead some of our more enterprising—or shall I say more visionary—associates to dream about how pleasant it would be if we owned the house. Such dreams may cause us to forget our proper place and if indulged in too long may result in unbearable insubordination with the usual consequences. Perhaps if we kept ourselves busier at our job we would not have time for such dreams and we would accomplish more for our masters and for ourselves.

Let me sketch briefly my own experiences, which lead me to this point of view. First, what are we representatives of the professional societies supposed to do?

According to the rules of procedure, "The representatives of each participating body shall be charged with the responsibility of providing its governing board with current information about the plans, program, and proceedings of ECPD, supplementing the reports of the secretary, and of ascertaining the official attitude of its governing board on matters under discussion before ECPD." When I think of this rule and of the actual performance of one of the representatives of one of the participating bodies, I find a reason for the apparent lack of lively interest on the part of that particular body.

In telling my story, I must of necessity make references to persons and events. No criticism is intended or implied.

EXPERIENCES OF A REPRESENTATIVE

When I was first appointed as a representative of AIEE, I knew perfectly well that the appointment must represent a job, since I had not arrived at that time of life when my professional attainments entitled me to be the recipient of honors. So with eager inquisitiveness, I accepted the invitation to attend the next annual meeting of Council after notice of my appointment. I knew little or nothing about ECPD, so I listened carefully. I was much impressed and thoroughly imbued with the idea that here was a chance to be of tangible service to the profession. Then I respectfully waited for an assignment to duty or some instruction either from my master or my companions in service. I waited. A whole year passed. Nothing happened. This bothered me. I began to conceive of myself as the forgotten man, but I also decided that perhaps it was up to me to do something about it. The first annual meeting to which I would be a fully accredited representative was approaching and I thought I ought to try to find out what had been happening during the past year, so that I might take part more intelligently in the business of that meeting. Just at that time there came to me a copy of a draft of the revised pamplet, "Engineering—A Career, A Culture," with an implied invitation to read and comment constructively upon it. Here at last was a job and I went to it with enthusiasm. I received a polite acknowledgment of my letter of comment, so I dared to hope that some of my suggestions might be deemed substantial enough to be incorporated. Imagine my chagrin at the annual meeting when I found that none of them had been. However, I was interested to observe that several other representatives had the temerity to raise questions about some of the same points. Apparently the matter was not closed. I therefore continued my efforts to be constructively helpful.

At this same meeting I was puzzled by the manner in which it was proposed to obtain approval of the participating bodies of the release of this pamphlet for publication. Copies were to be sent to all the members of the governing boards of the participating bodies, but without making any specific recommendation. I arose timidly in the meeting and made the suggestion that it would be helpful to me, were I a member of one of these boards, to be told specifically what ECPD thought about this pamphlet, what they suggested be done with it and why and for how much. The suggestion was ruled out of order as being prejudicial to objective consideration of the pamphlet by the recipients.

A few days after the meeting, I addressed a communication to my two associates representing the same participating body, appealing to their greater length of experience for guidance. I am a rather outspoken individual and I put my request in these words, "I have been trying to ascertain just what a representative of a constituent body is supposed to do, other than attend meetings, look wise, and say 'yes' at appropriate intervals." Now admittedly that is a tough question—I might say it is almost a "Scottian" question. My two experienced associates did their best to be consoling but I remained unenlightened. I followed this up by consultations with assorted past presidents, vice-presidents, and directors, past and present, and got about the same

*ECPD SHOULD LOOK AHEAD, R. E. Doherty, ELECTRICAL ENGINEERING, July 1941, pages 318–21.

kind of encouragement. No one had anything specific to suggest, but everyone was willing to have me start something. They would all be right behind me—how far behind was not entirely clear to me.

I didn't do much during the second year, except faithfully attend the few brief meetings of the executive committee to which I had been appointed, and make a scouting expedition on my own to see how the pamphlet was making out in its review by the members of the governing body of AIEE. I started by looking at the replies that came in to headquarters, most of which indicated to me that the pamphlet had not been read. I took my courage in my hands and called on a number of these officers and directors with whom I had a speaking acquaintance. I generally drew the reaction, "Oh, were we supposed to read it?"

During the third year, I stopped running around asking questions and put that same energy, hitherto wasted, to work, in more productive activities. These activities have obtained for me a somewhat questionable recognition by our chairman. I have been given the job of stirring up interest and a feeling of responsibility on the part of the members and officers of the professional societies who may be within sound of my voice and I have assumed for myself the job of stirring up my associates on the Council.

My experiences in that capacity derived of the past three years have served to strengthen my conviction that one gets specific answers to specific questions and general answers, if any, to general questions and that engineers as a group are no different from the rest of humanity in their actions and reactions.

SUGGESTIONS TO SOCIETIES AND REPRESENTATIVES

First, I should like to clean up that part of my assignment dealing with our masters, the officers and members of the participating bodies. My first suggestion to them is that they exercise the greatest care in choosing their servants, bearing in mind that the assignment as representative is not an honor—it is a job.

There is a common fallacy which holds that the busier a man is the more jobs he can take on and the better he will do them. To me this sounds like getting something for nothing. As engineers, believing in the principle of conservation of energy, we should know it just can't be so. Accordingly, a participating body would do well to choose an individual who is reasonably sure that he will have the time to give to the job that the job requires.

ECPD is spending money which the participating bodies supply. The officers and directors of the participating bodies therefore should review periodically what they are getting for the money of their members, to what extent the profession is being advanced as a result of that expenditure, and whether the most effective use is being made of the time and money being expended on their behalf.

Above all things, avoid the common mistake of setting up more committees or new agencies to do the same job. Face the issue squarely and insist that the existing committees and the existing agencies produce or show cause why they cannot. The temptation to start some new group is always a strong one but in the end makes the confusion worse confounded. I submit that a continuing interest and sustained effort are essential factors in the success of any enterprise.

To my fellow representatives my first remark is a corollary of what your sponsors should do in your selection. If, having accepted the job, you find that for any reason you can't see it through with the thoroughness which you know it deserves, or if you just plain don't like it after you have tried it, why not quietly withdraw so that the assignment may be given to someone who has the time or a more active interest or is otherwise better able or better fitted to carry on?

Let's resolve not to ask our principals what they think. Let's tell them what we think and why and what we believe should be done about it. Let them gain respect for us and for their joint enterprise by the way we conduct our business.

After two years of running around trying to find out what other people thought I as a representative should do, or what ECPD should do, I had the very great pleasure of going before the AIEE board of directors with two specific propositions, one of which cost them money, and obtaining their enthusiastic response and prompt action on both proposals. On that same occasion, after obtaining favorable action on the things I specifically requested, I made a general request for ideas, suggestions, and criticism, which was politely received, but to which I have had no reply then or since from the group as a whole, or from any individual member thereof.

NEED FOR A UNITED FRONT

Of course, before we approach our principals with specific proposals, we should be sure that our proposals are sound and reasonable, that they are definitely a part of our general assignment, and that they are important steps in the attainment of our objective. Moreover, in my opinion, it is important that Council, as a whole, present a united front on all such matters. If we cannot agree among ourselves, it is unlikely that the participating bodies we represent will agree.

Even after we have made a sale, our job is not done. Obviously if we are asking for authority for ourselves to do a job and we get that authority, we are obligated to go to work anew. On the other hand, if our recommendation calls for action by some other agency, such as a committee of one of the participating bodies, we should personally see to it that the committee thoroughly understands the job given it to do, and do everything in our power to promote its success. In either case, we cannot relax.

CURRENT PROBLEMS

In the course of preparing these remarks, I reviewed our last annual report. The first thing that hit me was the fact that the only policies listed as adopted by Council are dated October 1933. Does this mean that we found all the answers in October 1933? Obviously, no. To me, it means that we started with enthusiasm, then the going got a little hard, then we began to get cautious, then we began to debate more over the form than the substance. We lost our courage. It was easy to talk but hard to arrive at a conclusion.

What effective action have we taken on the recommendations contained in the reports of our committees? I think I can say the answer as to fundamental recommendations is somewhat embarrassing. To be sure, we did grant the request of the several committees for funds for use during the year, but neither collectively nor individually, so far as I am aware, did we really implement the basic recommendations which we ourselves presumably approved in accepting the committees' reports. Do we seriously expect that anything is going to happen just because a committee makes a report, we accept it for the record, and it is published in our annual report? I don't think we really do if we are honest with ourselves. We probably hope that somebody will do something about it—but somebody else, not me.

Let me suggest just two sample items about which we should be up and doing. Our Committee on Student Selection and Guidance made some suggestions about stimulating the local sections or chapters of our participating bodies to new or renewed efforts in that field. Frankly, it took me nearly a year to give them a hand and then it came about by accident, rather than by design on my part. Similarly, the Committee on Professional Training made certain recommendations as to work that might be handled by local groups in their field of activity. I have done nothing about this and it is on my conscience.

What agency is better organized than ECPD to reconcile the divergent points of view on the so-called model law? To be sure it is not a specific assignment, but it certainly comes within our general scope and we might materially enhance the prestige of the profession if we could get the various societies we represent to stop fighting with each other more or less publicly about model laws and to turn over to us the job of drafting a model law which would take into account not so much diverse points of view as the actual realities of engineering practice. If we cannot do a job like that there is not much excuse for our existence.

There are many problems common to all branches of the profession. Their solution is intimately related to the enhancement of the professional status of the engineer. That is our job. Shall we do it? My answer is—Yes. When shall we begin? My answer is—Now.

Better Understanding of ECPD Objectives Stressed at Ninth Annual Meeting

RECOGNITION of the need for a more general understanding of the major objectives of the Engineers Council for Professional Development among its constituent societies, and constructive suggestions from the official representatives of these sponsoring bodies featured the ninth annual meeting of ECPD, held October 31,

1941, at the Engineering Societies Building, New York, N. Y.

In introducing his report on the work of Council for the past year, its chairman, Doctor Robert E. Doherty, president of Carnegie Institute of Technology, declared that before ECPD could accelerate its progress toward the objectives stated in the charter, it was essential that "not only the officers and boards but also the rank and files of the constituent organizations understand much more fully than they have in the past what these objectives are and the importance of their achievement to the welfare of the country." "An astonishing number of people, including some comparatively close to the work, have felt that the most important activity and the only significant achievement of ECPD have been in connection with the accrediting program," Doctor Doherty said, pointing out that the Charter clearly indicates other purposes and activities relating to selection and guidance, professional training, professional recognition. "From the point of view of further advancement of the profession, and more important still, the welfare of the country, these other purposes and activities are, in the long run, unquestionably of equal importance with accrediting," he said.

Recalling that at the beginning of the year he had strongly urged an educational campaign among the constituent organizations as one of the most important projects the Council could undertake, Doctor Doherty stated his confidence that "as the constructive purposes and results of the Council's work become clear, all constituent bodies will appraise the situation as it exists today, forget misunderstandings of the past, and see their way clear to support the Council's work." He described the projects represented by ECPD's standing committees "and by other objectives having to do with professional development" as affording a basis upon which effective co-operation among the societies can be developed. "But the effectiveness of this co-operation will depend, in my opinion, altogether upon the effectiveness of plans devised by the Council to make use of the machinery wisely set up when it was organized. These plans must, it seems to me, include a more active participation than in the past by the representatives of the constituent bodies; and to accomplish this, there naturally must be a definite and constructive program in which they can find an active interest . . . . The officers and committee chairmen of the Council must work with the delegates to formulate plans and procedures. Fostering co-operative effort has thus become one of our definite plans."

Three steps already taken in the educational campaign, Doctor Doherty said, were his own report to the boards of the societies, "ECPD Should Look Ahead" (*EE, July '41, p. 318–21*); the plan of the committee on information to prepare informative press releases on Council's work, especially publications reaching the engineering profession; and finally a plan to encourage sessions for discussion of ECPD's work at meetings of the societies. Two such meetings have been held and two more are contemplated in this connection he called attention to a suggestion by AIEE Representative J. F. Fairman that the way to achieve understanding and active interest by the societies in ECPD is through their local sections, and that the way to bring this about, in AIEE for example is to have a plan presented and discussed at the conference of officers, delegates, and members, held annually at the summer convention. Of the Council's problems the one most likely to attract Section action, according to Mr. Fairman, is student selection and guidance; a second, suggested by Doctor Doherty, is the work of the committee on professional training among young graduates.

Doctor Doherty's report also touched upon high lights of the work of ECPD's various committees, all of which presented detailed reports at the meeting.

Figures on the progress of the accrediting program were presented by the committee on engineering schools, of which A. A. Potter of Purdue University was chairman. Nearly all the institutions in the United States which grant degrees in engineering have voluntarily submitted curricula for inspection by the Council's committee on engineering schools since the beginning of the accrediting program in 1933, that committee's report shows. In 143 of 166 such institutions, 896 curricula have been inspected, including reinspection, since 1939, of 158 curricula. One or more curricula have been accredited in 129 schools. Accredited curricula number 460; provisionally accredited 105; action was deferred on 6; and accrediting has been refused to 167. Reinspections resulted in change of status for only 26 curricula, in no change for 132. With the inspection program virtually complete, the committee is now engaged chiefly with reinspections of those curricula provisionally accredited.

The short engineering courses provided by the Engineering Defense Training program should not receive credit toward degrees, the committee on engineering schools recommended, pointing out this would interfere with the primary objective of the courses. The defense program has highlighted the lack in the United States of facilities for technical education of a grade between the engineering college and the vocational school, the committee noted, announcing the appointment of a subcommittee to work with the Society for the Promotion of Engineering Education to develop a program for accrediting technical institutes. Attention was called to the increase in engineering schools operated for private profit and granting engineering degrees under existing state laws. A year's study in such schools, in the opinion of the committee, is not equivalent to a year in an accredited curriculum. The committee also recommended that the Engineers' Council for Professional Development continue its policy of limiting the variety of engineering curricula accredited, accrediting specialized curricula only as options under accepted general curricula.

Recognition that the defense program and the probable employment problems following the emergency affect the relationship of younger engineers to their professional societies was indicated in recommendations of the Council's committee on professional training, urging immediate consideration of these problems. This committee also recommended that the national engineering societies hold clinics for professional guidance.

A study of the bases of selection of engineering students to be made jointly by the Society for the Promotion of Engineering Education and the Engineers' Council for Professional Development was recommended by the latter's committee on student selection and guidance, which continues also to encourage engineers to carry on guidance work among high-school students in their communities. A new ECPD guidance booklet, "Engineering as a Career," authorized for immediate publication, is expected to be available soon to take the place of the booklet "Engineering—A Career, A Culture," which is out of print.

During the past year, the Engineers' Council for Professional Development took over the sponsorship of a joint committee on engineering ethics, representing several national engineering societies, and sponsored by the American Engineering Council until the dissolution of that body. Reporting preliminary work in the drafting of a canon of engineering ethics, the committee recommended that a statement on the influence of ethics on the basis of a profession be prepared by the Council's committee on professional recognition. The latter committee reported continued study on the problems related to professional recognition.

Reports of the representatives of ECPD's constituent bodies also reflected the growing interest in closer co-operation. They were concerned chiefly with comments and suggestions on the work of the Council and activities of the societies in support of the work.

J. B. Challies, speaking for the Engineering Institute of Canada, which joined the group of ECPD sponsor societies in 1940, expressed that organization's enthusiasm about ECPD's achievements and discussed the background of organized engineering in Canada and the EIC's activities in initiating a model engineering registration law. While the war economy of necessity limits present activities, the EIC has set up a committee concerned with "servicing the young engineer" and is preparing a Canadian edition of "Engineering as a Career".

Hope for greater understanding and co-operation between the American Institute of Chemical Engineers and ECPD was expressed by S. D. Kirkpatrick, who spoke of the special position of that organization

(*Continued on page 610*)

Notes on List of Accredited Curricula

(See Facing Page)

(*a*). Accrediting applies to both the day and evening curricula.

(*b*). Accrediting applies to the 4-year and 5-year curricula leading to the bachelor of science degree.

(*c*) Accrediting applies to day and to 6-year evening curricula in the Cooper Union Night School of Engineering as submitted to ECPD.

(*d*). Accrediting applies only to curriculum as submitted to ECPD and upon completion of which a certificate is issued by Harvard University certifying that the student has pursued such a curriculum.

(*e*). The accrediting of a curriculum in general engineering implies satisfactory training in engineering sciences and in the basic subjects pertaining to several fields of engineering; it does not imply the accrediting, as separate curricula, of those component portions of the curriculum such as civil, mechanical, or electrical engineering that are usually offered as complete professional curricula leading to degrees in these particular fields.

(*f*). On July 24, 1940, Illinois Institute of Technology was formed by the consolidation of Armour Institute of Technology and Lewis Institute. Curricula now listed under Illinois Institute of Technology were formerly listed under Armour Institute of Technology.

List of Undergraduate Curricula Accredited by ECPD as of October 30, 1941

(Subject to revision. For basis of accrediting see ELECTRICAL ENGINEERING, December 1938, page 515)

Akron, University of: Electrical, mechanical (industrial and aeronautical options)

Alabama Polytechnic Institute: Civil, electrical, mechanical

Alabama, University of: Aeronautical, civil, electrical, industrial, mechanical, mining

Alaska, University of: Civil, mining (including metallurgical and geological—options)

Arizona, University of: Civil, electrical, mechanical, mining

Arkansas, University of: Civil, electrical, mechanical

Brooklyn Polytechnic Institute: Chemical (day and 8-year evening), civil[a], electrical[a], mechanical[a]

Brown University: Civil, electrical, mechanical

Bucknell University: Civil, electrical, mechanical

California Institute of Technology: Aeronautical (5- and 6-year courses), chemical (5-year course), civil, electrical, mechanical

California, University of: Civil, electrical, mechanical, metallurgical (metallurgy), mining, petroleum

Carnegie Institute of Technology: Chemical, civil[a], electrical[a], industrial (management)[a], mechanical[a], metallurgical[a]

Case School of Applied Science: Chemical, civil, electrical, mechanical, metallurgical

Catholic University of America: Aeronautical, architectural, civil, electrical

Cincinnati, University of: Aeronautical, chemical, civil, electrical, mechanical

The Citadel: Civil

Clarkson College of Technology: Chemical, civil, electrical, mechanical

Clemson Agricultural College: Civil, electrical, mechanical

Colorado School of Mines: Geological, metallurgical, mining, petroleum

Colorado State College: Civil, electrical, mechanical

Colorado, University of: Architectural, civil, electrical, mechanical (includes aeronautical option)

Columbia University[b]: Chemical, civil, electrical, industrial, mechanical, metallurgical, mining

Connecticut, University of: Civil, electrical, mechanical

Cooper Union Institute of Technology: Chemical, civil[c], electrical[c], mechanical[c]

Cornell University: Chemical, civil, electrical, industrial (administrative), mechanical

Dartmouth College: Civil

Delaware, University of: Chemical, civil, electrical, mechanical

Denver, University of: Electrical

Detroit, University of: Aeronautical, architectural, chemical, civil, electrical, mechanical

Drexel Institute: Chemical, civil, electrical, mechanical

Duke University: Civil, electrical, mechanical

Florida, University of: Civil, electrical, industrial, mechanical

George Washington University: Civil, electrical, mechanical

Georgia School of Technology: Aeronautical, chemical (including co-operative curriculum), civil, electrical, mechanical

Harvard University[d]: Civil, communication, electrical, industrial (engineering and business administration), mechanical, metallurgical (physical metallurgy), sanitary

Idaho, University of: Civil, electrical, mechanical, metallurgical (metallurgy), mining

Illinois Institute of Technology (Armour College of Engineering): Chemical, civil, electrical, mechanical

Illinois, University of: Architectural, ceramic (technical option), chemical, civil, railway civil, electrical, railway electrical, general[a], mechanical, railway mechanical, metallurgical, mining

Iowa State College: Agricultural, architectural, ceramic, chemical, civil, electrical, general[a], mechanical

Iowa, State University of: Chemical, civil, electrical, mechanical

Johns Hopkins University: Chemical, civil, electrical, mechanical

Kansas State College: Agricultural, architectural, civil, electrical, mechanical

Kansas, University of: Architectural, civil, electrical, mechanical, mining

Kentucky, University of: Civil, electrical, mechanical, metallurgical, mining

Lafayette College: Civil, electrical, industrial (administrative), mechanical, metallurgical, mining

Lehigh University: Chemical, civil, electrical, industrial, mechanical, metallurgical, mining

Louisiana State University: Chemical, civil, electrical, mechanical, petroleum

Louisville, University of: Chemical, civil, electrical, mechanical

Maine, University of: Civil, electrical, general[a], mechanical

Manhattan College: Civil, electrical

Marquette University: Civil, electrical, mechanical

Maryland, University of: Civil, electrical, mechanical

Massachusetts Institute of Technology: Aeronautical, building engineering and construction, chemical, civil, electrical, electrochemical, general[a], industrial (business and engineering administration), mechanical, metallurgical (metallurgy), naval architecture and marine engineering (including marine transportation), public health, sanitary

Michigan College of Mining and Technology: Civil, electrical, mechanical, metallurgical, mining

Michigan State College: Civil, electrical, mechanical

Michigan, University of: Aeronautical, chemical, civil, electrical, engineering mechanics, mechanical, metallurgical, naval architecture and marine engineering, transportation

Minnesota, University of: Aeronautical, chemical, civil, electrical, mechanical, metallurgical, mining, petroleum

Mississippi State College: Civil, electrical, mechanical

Missouri School of Mines and Metallurgy: Ceramic, civil, electrical, metallurgical, mining (mine) (including petroleum option)

Missouri, University of: Chemical, civil, electrical, mechanical

Montana School of Mines: Geological, metallurgical, mining

Montana State College: Civil, electrical, mechanical

Nebraska, University of: Agricultural, architectural, civil, electrical, mechanical

Nevada, University of: Electrical, mechanical, mining

New Hampshire, University of: Civil, electrical, mechanical

New Mexico School of Mines: Geological (both mining and petroleum options), metallurgical, mining, petroleum

New Mexico State College: Civil, electrical, mechanical

New Mexico, University of: Civil, electrical, mechanical

New York, College of the City of[e]: Civil, electrical, mechanical

New York State College of Ceramics (at Alfred University): Ceramic

New York University: Aeronautical, chemical (day and 7-year evening), civil[a], electrical[a], industrial (administrative), mechanical

Newark College of Engineering: Civil, electrical, mechanical

North Carolina State College: Ceramic, civil, electrical, mechanical

North Dakota Agricultural College: Architectural, mechanical

North Dakota, University of: Chemical, civil, electrical, mechanical, mining

Northeastern University: Civil, electrical, industrial, mechanical

Northwestern University: Civil, electrical, mechanical

Norwich University: Civil, electrical

Ohio State University: Ceramic, chemical, civil, electrical, industrial, mechanical, metallurgical, mining (mine)

Oklahoma Agricultural and Mechanical College: Civil, electrical, industrial, mechanical

Oklahoma, University of: Architectural, chemical, civil, electrical, mechanical, petroleum

Oregon State College: Civil, electrical, mechanical

Pennsylvania State College: Architectural, ceramic (ceramics), chemical, civil, electrical, electrochemical, fuel technology, industrial, mechanical, metallurgical (metallurgy), mining, petroleum and natural gas, sanitary

Pennsylvania, University of: Chemical, civil, electrical, mechanical

Pittsburgh, University of: Chemical, civil, electrical, industrial, mechanical, metallurgical, mining, petroleum

Pratt Institute: Electrical, mechanical

Princeton University: Chemical, civil, electrical, mechanical

Purdue University: Chemical, civil, electrical, mechanical, metallurgical

Rensselaer Polytechnic Institute: Aeronautical, chemical, civil, electrical, industrial, mechanical, metallurgical

Rhode Island State College: Civil, electrical, mechanical

Rice Institute: Chemical, civil, electrical, mechanical

Rochester, University of: Chemical, mechanical

Rose Polytechnic Institute: Civil, electrical, mechanical

Rutgers University: Civil, electrical, mechanical, sanitary

Santa Clara, University of: Civil, electrical, mechanical

South Dakota State College: Civil, electrical, mechanical

South Dakota State School of Mines: Civil, electrical, general[a], metallurgical, mining

Southern California, University of: Petroleum

Southern Methodist University: Civil, electrical, mechanical

Stanford University: Civil, electrical, mechanical, metallurgical, mining, petroleum

Stevens Institute of Technology: General[a]

Swarthmore College: Civil, electrical, mechanical

Syracuse University: Chemical, civil, electrical, industrial (administrative), mechanical

Tennessee, University of: Chemical, civil, electrical, mechanical

Texas, Agricultural and Mechanical College of: Civil, electrical, mechanical, petroleum (4- and 5-year courses)

Texas Technological College: Civil, electrical, mechanical

Texas, University of: Architectural, civil, electrical, mechanical, petroleum (petroleum production)

Tufts College: Civil, electrical, mechanical

Tulane University of Louisiana: Civil, electrical, mechanical

Tulsa, University of: Petroleum (including options in refining and production)

Union College: Civil, electrical

United States Coast Guard Academy: General[a]

Utah State Agricultural College: Civil

Utah, University of: Civil, electrical, mechanical, metallurgical, mining

Vanderbilt University: Civil, electrical, mechanical

Vermont, University of: Civil, electrical, mechanical

Villanova College: Civil, electrical, mechanical

Virginia Military Institute: Civil, electrical

Virginia Polytechnic Institute: Ceramic, chemical, civil, electrical, industrial, mechanical

Virginia, University of: Civil, electrical, mechanical

Washington, State College of: Architectural, civil, electrical, mechanical (basic option), metallurgical, mining

Washington University: Architectural, civil, electrical, industrial (administrative), mechanical

Washington, University of: Aeronautical, ceramic, chemical, civil, electrical, mechanical, metallurgical, mining

Webb Institute of Naval Architecture: Naval architecture and marine engineering

West Virginia University: Civil, electrical, mechanical, mining

Wisconsin, University of: Chemical, civil, electrical, mechanical, metallurgical, mining

Worcester Polytechnic Institute: Civil, electrical, mechanical

Wyoming, University of: civil, electrical, mechanical

Yale University: Chemical, civil, electrical, mechanical, metallurgical (metallurgy)

(*Continued from page 608*)

in regard to accrediting and stated that its procedure had recently been "streamlined" for greater efficiency. In support of the accrediting program, the American Society of Civil Engineers, by recent action of its board of direction, has voted that student chapters at institutions where the civil-engineering curricula have not been accredited by ECPD by January 1, 1944, would have their charters withdrawn at that time, G. W. Burpee reported for ASCE. That society has suggested that ECPD limit accrediting to the five major engineering fields and general engineering.

Declaring that the presentation and discussion of representatives' reports should stimulate activity by the participating bodies and keep the representatives alert to tangible evidences of co-operation with ECPD, J. F. Fairman, AIEE representative, stated that arrangements had been made for the discussion of ECPD objectives and activities at the conference of officers, delegates, and members at the 1942 AIEE summer convention, to which Doctor Doherty had already referred. The AIEE committee on education plans to hold a conference at the 1942 winter convention and a session at the North Eastern District meeting in April 1942 on subjects relating to ECPD activities. The AIEE Sections committee has been studying ECPD proposals with reference to furthering student-guidance programs through local Sections.

Two suggestions for additional activities by ECPD were made by W. R. Chedsey, incoming representative of the American Institute of Mining and Metallurgical Engineers. One was preparation of a booklet offering guidance to engineering graduates, supplementing "Engineering as a Career"; the other was "the encouragement, and possibly some aid in direct development of personnel methods, through the use of scientific and engineering aids—in other words, assisting in the development of so-called human engineering." A booklet providing orientation for the engineering student and the recent graduate was also recommended by N. W. Dougherty, representing the National Council of State Boards of Engineering Examiners, who urged closer co-operation between that body and ECPD.

Joint sessions of ECPD and The American Society of Mechanical Engineers held in June 1941 were sponsored by the ASME committee on education and training for the industries, which also sent copies of ECPD's eighth annual report to section chairmen for study, R. L. Sackett reported for the ASME representative A. R. Stevenson, Jr.

More practicing engineers should be appointed to ECPD, particularly to the accrediting committee, according to R. A. Seaton, representative of the Society for Promotion of Engineering Education who characterized ECPD as "practically the only co-ordinating agency in the engineering profession". ECPD should also urge more participation by practicing engineers in the vocational guidance work of the societies and in the administration of engineering schools, he said. He also urged ECPD to work for greater uniformity among the engineering societies in admission and membership-grade requirements. SPEE has limited its institutional memberships in the United States to schools with accredited curricula, Dean Seaton reported.

Attendance at the annual meeting was much the largest ever recorded, partly because of the concurrent annual meeting of NCSBEE (see page 614). ECPD officers elected for 1941–42 are:

R. E. Doherty, president of Carnegie Institute of Technology, Pittsburgh, Pa., chairman (re-election); H. T. Woolson, executive engineer, Chrysler Corporation, vice-chairman (re-election); H. H. Henline, national secretary, American Institute of Electrical Engineers, New York, N. Y., secretary; A. B. Parsons, secretary, American Institute of Mining and Metallurgical Engineers, New York, N. Y., assistant secretary.

Newly elected committee chairmen are:

D. B. Prentice, president, Rose Polytechnic Institute, Terre Haute, Ind., committee on engineering schools; E. S. Lee, engineer, general engineering laboratory, General Electric Company, Schenectady, N. Y., committee on professional training; G. Ross Henninger, editor, American Institute of Electrical Engineers, New York, N. Y., committee on information. The following committee chairmen were re-elected for the coming year: R. L. Sackett, dean emeritus of engineering, Pennsylvania State College, New York, N. Y., committee on student selection and guidance; C. F. Scott, professor emeritus of electrical engineering, Yale University, New Haven, Conn., committee on professional recognition; D. C. Jackson, professor emeritus of electrical engineering, Massachusetts Institute of Technology, Cambridge, Mass., committee on engineering ethics.

Members of the executive committee are:

G. W. Burpee, consulting engineer, Coverdale and Colpitts, New York, N. Y., ASCE; A. R. Stevenson, Jr., General Electric Company, ASME; J. F. Fairman, Consolidated Edison Company of New York, Inc., AIEE; C. C. Williams, president, Lehigh University, Bethlehem, Pa., SPEE; B. F. Dodge, Yale University, New Haven, Conn., AIChE; C. F. Scott, professor emeritus, Yale University, NCSBEE; J. B. Challies, Shawinigan Water and Power Company, Montreal, Que., EIC; AIME representative to be appointed.

The executive committee will assume also the duties of the committee on ways and means.

Speakers at the 1941 annual dinner, held at the Engineers' Club, New York, October 30, 1941, included N. W. Dougherty, dean of engineering University of Tennessee, Nashville; A. H. White, president, SPEE; and J. F. Fairman, Consolidated Edison Company of New York, Inc. Mr. Fairman's talk appears on pages 606–07.

National Defense

Engineers Defense Board Established by Societies

To provide a central agency that will be prepared to assist the various branches of the government with engineering knowledge and experience on questions connected with military preparedness, six national engineering societies have joined to organize the Engineers Defense Board. Organization plans were completed during September, and since that time the Board and its executive committee have held several meetings. The most recent meeting was that held November 13 at Washington, D. C., jointly with the committee on metals and minerals of the National Academy of Sciences, at which "critical" materials formed the principal subject of discussion. Several committees have been appointed and already are giving attention to such problems as: steel conservation, waste materials, nickel and nickel-steel alloys, substitutes for copper, and aluminum.

Among the functions of the organization, as stipulated in its officially adopted statement of purposes and plan of organization, are:

1. To serve as a channel to inform engineers generally regarding defense problems, especially those involving shortages of materials.

2. To implement and make applicable reports and recommendations of the advisory committees of the National Academy of Sciences.

3. To urge engineers (*a*) to adopt procedures looking toward accomplishment of the objective of defense agencies; (*b*) to promote means of increasing production of raw materials in which shortages exist; (*c*) to conserve the supply of industrial materials; (*d*) to find substitutes; and (*e*) to simplify operations and production.

4. To act as a clearing house between engineers or engineering groups for information regarding substitute materials, waste prevention, and conservation.

5. To appoint, on request of the Army, Navy, or other defense agency, special committees of engineers to deal with specific engineering problems related to defense.

6. To select problems or projects dealing with defense and to study them with due regard to activities of existing agencies.

Initially, the Board consists of five representatives from each of the six participating societies: American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, AIEE, Society of Automotive Engineers, and American Institute of Chemical Engineers. To these may be added one or more representatives of such other national engineering societies as may be invited to participate, and such additional representatives of the six participating societies as may be requested. The activities of the Board are administered by an executive committee consisting of a chairman, a vice-chairman, and a secretary, elected by the other members of the executive committee, and one representative of each of the six participating societies appointed by the governing bodies of the respective societies.

R. E. McConnell, consultant, Office of Production Management, has been named chairman of the Engineers Defense Board; H. S. Rogers, president, Brooklyn Polytechnic Institute, vice-chairman; and A. B. Parsons, secretary, American Institute of Mining and Metallurgical Engineers, secretary of the Board. Representing the six participating societies, the following have been named members of the Board:

American Society of Civil Engineers. C. S. Proctor, consulting engineer, New York, N. Y.; R. E. Dougherty, vice-president, improvements and developments, New York Central System, New York, N. Y.; C. F. Goodrich, chief engineer, American Bridge Company, Pittsburgh, Pa.; R. R. McMath, chairman of the board, Motors Metal Manufacturing Company, Detroit, Mich.; J. P. H. Perry, vice-president, Turner Construction Company, New York, N. Y.

American Institute of Mining and Metallurgical Engineers. J. F. Thompson, executive vice-president, International Nickel Company, New York, N. Y.; Zay Jeffries, technical director, lamp department, General Electric Company, Cleveland, Ohio; Wilber Judson, vice-president, Texas Gulf Sulphur Company, New York, N. Y.; Frederick Laist, metallurgical manager, Anaconda Copper Mining Company, New York, N. Y.; Wilfred Sykes, president, Inland Steel Company, Chicago, Ill.

American Society of Mechanical Engineers. R. M. Gates, president, Air Preheater Company, New York, N. Y.; H. V. Coes, industrial department, Ford, Bacon and Davis, Inc., New York, N. Y.; K. H. Condit, dean of engineering, Princeton Uni-

versity, Princeton, N. J.; J. W. Parker, vice-president and chief engineer, Detroit Edison Company, Detroit, Mich.; W. R. Webster, chairman of the board, Bridgeport Brass Company, Bridgeport, Conn.

American Institute of Electrical Engineers. H. H. Barnes, Jr., commercial vice-president, General Electric Company, New York, N. Y.; C. A. Adams, consulting engineer, B. G. Budd Manufacturing Company, Philadelphia, Pa.; C. B. Joliffe, engineer in charge, frequency bureau, Radio Corporation of America, New York, N. Y.; R. L. Jones, director of apparatus development, Bell Telephone Laboratories, New York, N. Y.; Philip Sporn, vice-president in charge of engineering, American Gas and Electric Service Corporation, New York, N. Y.

Society of Automotive Engineers. C. L. McCuen, vice-president and chief engineer, General Motors Corporation, Detroit, Mich.; F. W. Caldwell, director of research, United Aircraft Corporation, East Hartford, Conn.; C. E. Frudden, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.; Arthur Nutt, vice-president, Wright Aeronautical Corporation, Paterson, N. J.; N. G. Shidle, editor, SAE *Journal*, New York, N. Y.; J. C. Zeder, chief engineer, Chrysler Corporation, Detroit, Mich.

American Institute of Chemical Engineers. F. W. Willard, president, Nassau Smelting and Refining Company, New York, N. Y.; Webster Jones, Carnegie Institute of Technology, Pittsburgh, Pa.; R. L. Murray, vice-president, Hooker Electrochemical Company, Niagara Falls, N. Y.; A. J. Weith, manager of research, Bakelite Corporation, Bloomfield, N. J.; A. E. Wilson, president, Pan American Petroleum and Transport Company, New York, N. Y.

The executive committee, as now constituted, consists of Chairman McConnell, Vice-Chairman Rogers, Secretary Parsons, C. S. Proctor (ASCE), J. F. Thompson (AIME), R. M. Gates (ASME), H. H. Barnes, Jr. (AIEE), C. L. McCuen (SAE), and F. W. Willard (AICE).

Lighting and the Defense Program Discussed by Killian Before IES

The importance of good lighting as a tool in the national-defense program was stressed in an address by Thomas J. Killian (A'35) technical director, The Frink Corporation, Long Island City, N. Y., at a "Residential Lighting Forum" held recently by the Illuminating Engineering Society. Mr. Killian discussed not only the vital role of lighting in industrial defense production, but also the place of residential lighting in the defense program. He also outlined the efforts being made by manufacturers of lighting equipment to conserve critical materials through simplification of design and the use of substitute materials. Essential substance of Mr. Killian's address follows.

Good lighting has proved to be a powerful tool in the defense program. It is now increasingly recognized that high levels of illumination promote speed, accuracy, sustained production effort, and safe operation. Industrial engineers and architects have installed levels of illumination ranging from 25 to 100 foot-candles, which increase the ease and speed of seeing, reduce eye strain and fatigue, and give all employees an equal opportunity to see naturally, whether working near windows or away from them. It is an obvious truism that good artificial illumination makes possible better utilization of floor space and permits arrangements of machines, work tables, and production lines for a most efficient sequence of operations, with little or no dependence upon natural-lighting facilities. This makes 24-hour operation practical with no penalty to the night shift.

Good illumination has made possible the now famous windowless buildings and blackout plants. In England it has been found that in blacked-out factories good lighting is essential for the morale of the workman as well as his health. In the *Transactions* of the British Illuminating Engineering Society for June 1941 appears the following pertinent statement:

An illumination level of 30–35 foot-candles is provided in the plant of the Kelsey-Hayes Wheel Company, Detroit, Mich., by two-lamp fluorescent units using 100-watt white lamps, spacing 10 feet by 13 feet 4 inches, mounting height, 15 feet

"Experience has shown that a few months work in a blacked-out factory may result in marked deterioration in physical and nervous condition, a waste of vital human assets. Faulty lighting produces eye strain, which in turn causes nervous disorder and the lighting engineer has a greatly increased responsibility for industrial health when the eyes are denied lengthy recuperative periods in natural daylight."

It is obvious from the plants now built or being built that the Government recognizes lighting as a powerful tool in its national-defense program. This is proved by the fact that industrial-lighting equipment is given the same priority as machine-tool equipment. In commercial lighting it is also realized that the speed and accuracy of the eye has a greater influence on the speed and accuracy of all kinds of defense work than any other factor. Carefully engineered commercial equipment has been specified and used in drafting rooms, engineering departments, offices, schools, and other important areas.

RESIDENTIAL LIGHTING

When we come to the subject of residential lighting, we find again that the Government recognizes that good lighting is essential to the health and morale of all, and especially the defense workers. The first major step in this recognition is the project-priority-rating plan for privately financed real-estate developments of low-cost housing in defense areas. These ratings will insure materials for the building of up to 200,000 homes throughout the country. The ratings are applicable to materials on the defense-housing critical list of the Office of Production Management, which includes electrical-wiring supplies, devices, and lighting fixtures. As in other types of lighting fixtures the use of aluminum and solid brass or bronze is barred, but copper and brass plating is permissible. Indoor fixtures must be of light-gauge spinnings, stampings, or drawings and nonmetallic elements must be used wherever practical. Outdoor fixtures must be of cast or wrought ferrous metals. There will also be provided additional materials for over 100,000 defense housing units being built by the Government.

So far there have been few restrictions regarding the production of lighting equipment. However, there is a definite shortage of metals, which at present is in the following order: magnesium, aluminum, nickel, copper, zinc, lead, iron, and steel. Manufacturers are doing all they can to substitute and conserve critical metals. Some specific examples of what they are doing are as follows:

1. The use of nickel has been eliminated in the manufacture of lamps and lighting fixtures.
2. As no aluminum has been available since October 1, steel and ferrous metals have, in general, been substituted.
3. Ferrous metals have been substituted for brass in the production of screw-machine parts.
4. Glass and plastics are being substituted for metals wherever possible.
5. The thickness or gauge is being reduced as far as possible without increasing hazards.
6. The tubing or shell for pipe suspensions is being eliminated wherever possible.
7. Designs are being simplified and ornaments with no practical purpose are being eliminated.
8. Ceiling canopies are being simplified.
9. Further simplification has been obtained by a reduction in the number of catalog items.

Because the situation is changing so rapidly, it is difficult to draw specific conclusions. However, manufacturers are urged to avoid "panic" buying, thus paying speculator's prices for materials; not only is this costly, but would invite further Governmental control. To substitute, reclaim, and conserve critical materials is the way to extend and expedite our defense effort. There is a reasonable chance that intelligent study and application of new materials will forestall dangerous reduction in quality of the equipment. The lighting industry is a tool industry, defined as a means for doing work.

If the greatness of a tool is measured by its capacity for doing useful work, we can forecast for lighting a medal of honor in the national-defense program.

All Critical Materials to Be Allocated

Preparation for the allocation of all critical materials throughout American industry was called for November 7, in parallel actions by the Supply Priorities and Allocations Board and the Office of Production Management. SPAB announced that it had authorized its executive director to request OPM to obtain detailed production programs, industry by industry, for 1942. It stipulated that these programs should contain ample information to indicate the month-by-month requirements of critical materials needed for the production of military, industrial, and civilian items, and essential public services. It also directed that these programs should show similar requirements for repair parts and capital expenditures. OPM issued an administrative order setting up the machinery by which the whole program of requirements is to be developed, outlined the manner in which the various industrial branches and other units of OPM are to work together toward this end, and instituted a new system of handling preference ratings in harmony with this program. The program is expected to give greater certainty to American business and industry, and a clear over-all picture of the nation's total requirements for raw materials to defense officials.

In substance the development of an allocation program will proceed roughly as follows: An industrial branch in OPM takes the first step, calling on its several sections to develop requirements programs for each industry that manufactures the products for which the branch is responsible. Each program is built up by the branch or by its section, through consultation with the industry advisory committee involved and also through discussion with either or both of the armed services, depending on the nature of the product and the materials used in its manufacture. When this has been done, the officers of the industrial branch who have the program in charge discuss the entire matter with the industrial branches that have jurisdiction over the materials or the products out of which the article in question is made. Agreement is reached between the branches as to the amount of material that can be allocated, and so on.

Thus, in effect, each program would originate with the group which is responsible for the end product, the raw-materials groups coming into the picture in an advisory and consultative capacity. Since all programs must be decreased or increased as armament production rises, each one will be framed so that it can be modified upward or downward in case of need. When a program has been drawn up, it will be reviewed carefully in order to cut down the use of critical materials to the greatest possible extent through simplification of lines, substitution, and so on. The OPM Bureau of Industrial conservation will work with and through the industrial branches to accomplish this.

CONSERVATION THROUGH SIMPLIFICATION URGED

Manufacturers in every field are being urged by the Bureau of Industrial Conservation to consider how they might reduce the number of varieties or styles of their products. Such a simplification program is needed to save vital materials for national defense as well as for civilian supply. Proposals by each industry for simplification programs will be welcomed by the Bureau, which is also prepared to aid and advise each industry on the subject. In addition, industry advisory committees, already set up within OPM to deal with problems springing from the demands of the defense program, will be used to work out programs of simplification.

It is the task of the Bureau of Industrial Conservation to inaugurate and conduct a "war on waste" combining and expanding to a great degree all previous efforts aimed at conserving the nation's resources. Simplification is being urged by the Bureau as one of the most direct and important methods of conservation of critical materials.

Power Curtailment in Southeast Postponed

Moderate to heavy rains, plus increased power deliveries into the shortage area through power-pooling arrangements have made possible postponement of the power-curtailment program originally scheduled to go into effect November 10 in seven Southeastern states. The 30 per cent curtailment scheduled for Georgia, Tennessee, Alabama, East Mississippi, Southeast North Carolina and Northwest Florida was postponed for a limited time; the 5 per cent curtailment scheduled for the remainder of South Carolina and North Carolina was postponed indefinitely. Immediate and willing cooperation by the public with the "blackout" provisions of the order affecting nonessential lighting services also contributed to the improved situation. The "blackout" provisions, however, will continue in effect in the entire area.

The original program called for:

1. Curtailment of power by large commercial and industrial users in seven states (vital defense industries and a few others providing essential civilian services exempt).

2. Immediate discontinuance of the use of power for such nonessential services as sign lighting, show-window lighting, and floodlighting of athletic fields.

3. Immediate mandatory pooling of power by interconnected systems of 40 publicly and privately owned companies in 13 states.

Rapidly mounting power needs caused by new and expanding defense industries and prolonged drought conditions created the shortage, which has been estimated as high as 72,000,000 kilowatt-hours a week by J. A. Krug, head of the power section, Office of Production Management. Under the general limitation order issued October 30 by Donald Nelson, director of priorities, a consumer could use up to 10,000 kilowatt-hours per month at a rate of not more than 2,500 kilowatt-hours per week without being curtailed. Thus residential and small commercial consumers would not be affected, except that they may not use power for the prohibited services. The curtailment order would apply to every nonexempt consumer who used more than 10,000 kilowatt-hours during the month for which his meter was read between September 15 and October 14, inclusive.

Exemptions from the curtailment order were provided for operations found by the director of priorities to be essential to national defense or to essential civilian services. Seven groups of consumers were listed as exempt from the mandatory curtailment provisions. They include:

1. The following federal, state, county, and municipal services: fire, police, and essential state and highway lighting.

2. The following essential community services: churches, hospitals, newspapers, refrigeration, and food-preservation plants.

3. Transportation services, street cars, railways, waterways, airports, oil and gas lines and pumping stations, and shops used exclusively for transportation services.

4. Communications services, including postoffices, radio, telephone and telegraph, and traffic control.

5. Waterworks, pumping stations, and sewage-disposal plants.

6. Military establishments.

7. Plants exclusively engaged in the production of any of the following munitions or materials: airplanes and airplane engines; naval ships; merchant ships; ordnance items including guns, ammunitions, explosives, and combat vehicles; aluminum; magnesium; copper or brass; zinc; manganese; mercury; ferroalloys; abrasives; graphite electrodes; forgings; machine tools; artificial gas.

New Defense Plant Construction

Among recently reported industrial-plant construction projects related to the national-defense program are the following:

Aluminum Company of America. To supply stock for the manufacture of forgings for airplane motors and fittings, and rod, bar, and wire for national defense industries, this company plans to erect a second blooming mill at its Massena, N. Y., works. The mill and its necessary facilities will be housed in steel and brick buildings to cover an area of more than 450,000 square feet, and its estimated total cost exceeds $15,000,000. A completely new melting department will be established to serve the blooming mill.

Allis-Chalmers Manufacturing Company. A 500- by 800-foot single-floor windowless building to cost more than $9,000,000 is being constructed by this company in suburban Milwaukee, Wis., for the production of airplane superchargers. Scheduled for completion in about six months, the building will be air-conditioned throughout and lighted by fluorescent units. The electrical substation for the plant's power supply will be completely enclosed and protected against the effects of possible bombing.

Fairbanks Morse Company. More than 300,000 square feet of floor space will be provided in a new Diesel-engine plant being built by this company in Beloit, Wis., at a cost of $5,500,000. It will have a frontage of 660 feet and a depth of 460 feet. Production is expected to be under way in about a year.

General Electric Company. Plans for the construction of a new $1,000,000 plant in Pittsfield, Mass., for the manufacture of synthetic phenol, were announced recently by this company. The plant, which is expected to be in operation by September 1942, will comprise four structures.

Mobile Power Plants for Navy. The Bureau of Yards and Docks, Navy Department, has ordered two 10,000-kw mobile steam-electric power plants mounted on

special railway cars from the General Electric Company, Schenectady, N. Y., to supply emergency power wherever its projects may require. One unit will be centrally located on the West Coast and the other on the East Coast. Each of the two units will be housed in two specially built railway cars which can be hauled over the rails at speeds up to 40 miles per hour. The power-generating car will contain a 10,000-kw turbine-generator and accessories, a condenser, and the necessary switchgear. The boiler and its auxiliaries, together with a starting engine-generating set will be housed in the second car. The boilers will be oil-fired and will furnish 140,000 pounds of steam per hour; steam conditions: 550-pounds per square inch, 825 degrees Fahrenheit. The turbines will be of single-cylinder design. The three-phase 60-cycle generators will operate at 3,600 rpm, and the generated voltage will be 13,800 volts.

Westinghouse X-Ray to Move. The administrative departments of the X-ray division of the Westinghouse Electric and Manufacturing Company will be shifted from Long Island City, N. Y., to the radio-division plant at Baltimore, Md., about January 1, 1942, according to a recent announcement by the company. Manufacturing departments, at work on vital X-ray equipment for the armed forces, the medical profession, and industry, will continue in the division's Long Island City factory; manufacturing space will be increased 26 per cent by the move. Scientific and engineering activities for the two divisions will be centralized at Baltimore.

Positions to Be Filled Through Civil Service Examination

Notice of the following positions, which will be filled through civil service examinations, is published here as a service to members of the Institute. Application forms and full information as to requirements for examinations may be obtained from the secretary of the Board of United States Civil Service Examiners at any first- or second-class post office, or from the United States Civil Service Commission, Washington, D. C. Unless otherwise noted, applications will be accepted until further notice.

Radio Mechanic-Technicians (Amended Announcement). A sufficient number of persons did not apply for the radio mechanic-technician positions announced by the Civil Service Commission on September 8, 1941 (*EE, Oct. '41, p. 512*). Accordingly, the examination announcement has been amended:

a. To make it "open continuous", that is, applications will now be accepted until further notice;

b. To add the position of chief radio mechanic-technician at $2,600 a year;

c. To modify the experience requirements and to provide for the substitution of education for part of the experience.

Naval Ordnance Materials Inspectors. In June of this year the U. S. Civil Service Commission announced that it was recruiting inspectors of naval ordnance materials (*see EE, July '41, p. 359–60*). Appointments are being made at the Washington (D. C.) Navy Yard, Naval Torpedo Station in Alexandria, Virginia, and at various contractor plants in the field. The examination announcement covering these positions has just been issued in revised form. The need of the Navy Department for junior inspectors ($1,620 a year) is particularly pressing. The possibility of advancement is good. Requirements have been modified so that the successful completion of an appropriate approved National Defense Training course will meet the full requirements for this grade.

Revised Aeronautical Engineering Inspectors Examination. The examination for inspectors of aeronautical engineering materials (*see EE, Apr. '41, p. 191*) has just been reissued, liberalizing the provision for using National Defense Training Courses. The completion of *any* appropriate engineering defense training course will now be accepted for one year of the prescribed education or experience. There is a particular need for junior inspectors of engineering materials and for these positions applicants need only have completed an appropriate defense training course. Acceptable courses include those in tool engineering, gauging and inspection methods, instrument design, and related courses in materials inspection or engineering fundamentals and basic principles.

Other Societies

NRC Insulation Conference Held

Taking a modern topic into an historic setting, the National Research Council's 14th annual conference on electrical insulation was held at the Williamsburg Inn., Williamsburg, Va., October 30–November 1, 1941. The registered attendance was 72. Progress reports on the following 23 topics were presented and discussed:

1. The Polarization Parameters of Various Dielectrics Including Rubber and Their Changes With Temperature, R. F. Field, General Radio Company.

2. Susceptance Variation Measurements of Dielectric Constant and Dielectric Loss in Insulating Materials Between 1 and 50 Megacycles, S. I. Reynolds, General Electric Company.

3. An Investigation of the Dielectric Constant and Other Physical Properties of Benzene Solutions of Several Methacrylate Polymers, L. Ackerman, H. C. Ott, and O. M. Arnold, Rensselaer Polytechnic Institute.

4. A-C-D-C Correlation in Dielectrics, J. B. Whitehead and G. S. Eager, Johns Hopkins University.

5. Effect of Aging Semiconducting Rubber-Like Compounds in Insulating Oil, F. L. Downs, C. R. Boytano, and G. M. L. Sommerman, American Steel and Wire Company.

6. Liquid Dielectrics. Power Factor and Related Properties of Solutions of Sulfur and Nitrogen Compounds in Liquid Paraffins, J. D. Piper, The Detroit Edison Company.

7. Anomalous Relation Between Dielectric Strength and Paper Density, W. A. Delmar, C. N. Works, and J. H. Palmer, The Phelps Dodge Copper Products Corporation.

8. Temperature, Oxygen, and Stress in Impregnated Paper Insulation, J. B. Whitehead and W. H. MacWilliams, Johns Hopkins University.

9. The Dielectric Strength and Life of Impregnated Paper Insulation—III, J. B. Whitehead, Johns Hopkins University.

10. Some A-C Properties of Paper Dielectrics Containing Chlorinated Impregnants, D. A. McLean and C. C. Houtz, Bell Telephone Laboratories.

11. Effect of Flow in Molding on the Dielectric Constant and Power Factor of Rubber-Filler Systems, A. H. Scott, National Bureau of Standards.

12. Semiconducting Shielding for Cables, R. J. Merrell, The Phelps Dodge Copper Products Corporation.

13. The Impulse Strength of Solid and Gas-Filled High Voltage Cables, Andrew Gemant, The Detroit Edison Company.

14. Further Tests on Low Pressure Cable, J. A. Scott, General Electric Company.

15. Progress Report on Aging of Cable Insulation Subjected to Elevated Temperatures, Thorstein Larsen, Consolidated Edison Company of New York.

16. A New Test for Evaluating Electrical Insulating Oil, J. C. Balsbaugh and A. G. Assaf, Massachusetts Institute of Technology.

17. A Study of the Electric Hygrometer, R. N. Evans, Consolidated Edison Company of New York.

18. A Manometric Procedure for the Determination of Water in Insulating Oil, R. N. Evans, Consolidated Edison Company of New York.

19. Wax Formation in Stamp Capacitors, W. N. Arnquist and C. E. Trantman, Gulf Research and Development Company.

20. Dielectric Nomenclature, H. H. Race, General Electric Company.

21. The Effect of Corona Deposit on the Flash-over Voltage of Suspension Insulator Units, C. L. Dawes, Harvard University.

22. The Electrical Resistance of the Semiconductor Copper Iodide, R. J. Maurer, Massachusetts Institute of Technology.

23. Resumé of Recent Insulation Researches Undertaken by the Research Department of The Detroit Edison Company, H. S. Walker, The Detroit Edison Company.

Efforts are being made to complete a comprehensive summary of the essential substance of these reports, for publication in an early issue of ELECTRICAL ENGINEERING.

Doctor Ward F. Davidson (A'14, F'26) director of research for the Consolidated Edison Company of New York, Inc., will continue as chairman of the insulation conference for 1941–42. Doctor H. H. Race of the General Electric Company, Schenectady, who has been chairman of the committee on physics relinquished the chairmanship to his vice-chairman, Doctor von Hippel, and a new vice-chairman of that committee is to be appointed. Otherwise the executive committee remains unchanged as follows:

W. F. Davidson, Consolidated Edison Company, New York, N. Y., chairman

Future Meetings of Other Societies

American Association for the Advancement of Science. Winter meeting, December 29–January 3, 1942, Dallas, Tex.

American Institute of Mining and Metallurgical Engineers. Annual meeting, February 9–12, 1942, New York, N. Y.

American Mathematical Society. 48th annual meeting, December 29–31, 1941, Bethlehem, Pa.

American Physical Society. 245th meeting, December 19–20, 1941, Stanford University, Calif. 246th (annual) meeting, December 29–31, 1941, Princeton, N. J. 247th meeting, February 20–21, 1942, Detroit, Mich.

American Society for Testing Materials. Spring meeting, March 2–6, 1942, Cleveland, O.

American Society of Civil Engineers. Annual meeting, January 21–23, 1942, New York, N. Y.

American Society of Heating and Ventilating Engineers. 48th annual meeting and seventh international heating and ventilating exposition, January 26–30, 1942, Philadelphia, Pa.

American Society of Mechanical Engineers. Spring meeting, March 23–25, 1942, Houston, Tex.

Engineering Institute of Canada. 56th annual and general professional meeting, February 5–6, 1942, Montreal, Que.

First Pan-American Congress of Mining Engineering and Geology. January 11–20, 1942, Santiago, Chile.

Institute of Aeronautical Sciences. 10th annual meeting, January 28–30, 1942, New York, N. Y.

Society of Automotive Engineers. Annual meeting, January 12–16, 1942, Detroit, Mich.

S. O. Morgan, Bell Telephone Laboratories, New York, vice-chairman

Thorstein Larsen, Consolidated Edison Company, New York, secretary

Arthur von Hippel, Massachusetts Institute of Technology, Cambridge, chairman, committee on physics

R. N. Evans, Consolidated Edison Company, New York, chairman, committee on chemistry

G. T. Kohman, Bell Telephone Laboratories, New York, vice-chairman, committee on chemistry

C. F. Hill, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., chairman, committee on monographs

H. N. Curtis, Bureau of Standards, Washington, D. C.

W. A. Del Mar, Phelps Dodge Copper Products Corporation, Yonkers, N. Y.

J. B. Whitehead, The Johns Hopkins University, Baltimore, Md.

Perhaps the most actively discussed single topic at the Williamsburg conference was the rapidly increasing necessity for considering substitute materials for electrical insulation. Many traditional practices and materials in the field of electrical insulation are coming to feel increasingly the double impact of increased demand incidental to the national defense activities of the Western Hemisphere and the interruption of supply channels as the result of war conditions in the rest of the world. An informal symposium served as a sharp reminder of the fact that insulating materials important to traditional insulation practices have come from all parts of the world and that some of these distant sources—of shellac and high-grade mica, for example—already have been shut off or diverted so far as the Western Hemisphere is concerned. The effects of the situation will reach into practically every branch of the electrical industry which, in turn, underlies all industry. Research laboratories are busy with the development and application of new materials, new combinations of known materials, and with the improvement and development of domestic supplies. The general consensus seems to be that the end results of the present emergency and the efforts being made to meet it will be a general and material improvement in materials, processes, and practices.

As the Insulation Conference group is holding itself in readiness for close co-operation with other National Research Council defense activities, through the Division of Engineering and Industrial Research, no definite plans have been settled upon at this date with reference to the annual conference for 1942. ELECTRICAL ENGINEERING will report on this later.

Better Administration of Laws Stressed by Engineering Examiners

The desirability of more uniform practices in qualifying applicants, for registration, and of improvement in qualifications in certain states, were emphasized at the 22d annual meeting of the National Council of State Boards of Engineering Examiners, held in New York, N. Y., October 27–30, 1941. Registration was larger than for any previous meeting, with 35 of the 44 member boards represented.

The committee on qualifications for registration, noting wide divergence in the practices of the various boards, presented for approval an outline of requirements basic to a determination of competence, a set of general principles to be applied to interviews with applicants, and a set of general requirements basic to all branches of engineering, to be applied in determining whether the four years of qualifying experience usually required meet adequate standards. The latter general statement was supplemented by a detailed statement in regard to civil engineering. The committee's report was approved, and it was instructed to prepare similar detailed statements for the other major engineering fields.

Qualifications for registration are considerably below "model law" standards in about one fourth of the states, notably those with old registration laws, the committee pointed out, urging the Council to work for improvement of such laws.

The secretary of NCSBEE reported that with the passage of registration laws by three states during the current year, only three now lack such laws.

Specifically avoiding any related financial commitment, the Council approved a recommendation from the secretary that NCSBEE undertake the publication of a national directory of registered engineers if satisfactory arrangements can be made.

"Registration by endorsement" rather than reciprocal registration between states was urged by the committee on interstate registration, which pointed out that insistence on reciprocal registration is a form of coercion toward relaxing responsibility and lowering standards, whereas registration by endorsement is permissive rather than mandatory.

Development of a code of engineering ethics by the Engineers' Council for Professional Development was recommended as an objective for the near future, in connection with discussion of the desirability of requiring applicants for registration to endorse a code of professional ethics. Other matters of co-operation with ECPD were discussed.

Officers elected for the coming year are:

C. C. Knipmeyer (A'10, M'35) professor of electrical engineering, Rose Polytechnic Institute, Terre Haute, Ind., *president*; J. H. Dorroh, dean of engineering, University of New Mexico, *vice-president*; G. M. Shepard, St. Paul, Minn., and F. W. Anderson, Lexington, Va., *regional directors*. T. Keith Legaré continues as executive secretary.

National Electrical Safety Code Revision Completed

With the publication of part 2, "Safety Rules for the Installation and Maintenance of Electric Supply and Communication Lines", all six parts of the National Electrical Safety Code are now available in printed form. This represents the completion of a tremendous task by the American Standards Association Sectional Committee on the National Electrical Safety Code under the able leadership of the late Doctor M. G. Lloyd (A'08-F'12), as chairman.

Copies of the various parts of this Code may be ordered from the Superintendent of Documents, United States Government Printing Office, Washington, D. C. The titles, identifying numbers, and prices of each part of this Code are as follows:

1. "Safety Rules for the Installation and Maintenance of Electrical Supply Stations", Handbook H-31, 10 cents

2. "Safety Rules for the Installation and Maintenance of Electric Supply and Communication Lines", Handbook H-32, 05 cents

3. "Safety Rules for the Installation and Maintenance of Electric Utilization Equipment", Handbook H-33, 15 cents

4. "Safety Rules for the Operation of Electric Equipment and Lines", Handbook H-34, 10 cents

5. "Safety Rules for Radio Installations", Handbook H-35, 10 cents

6. "Safety Rules for Electric Fences", Handbook H-36, 05 cents

Machine Tool Builders Adopt New Standards. A new set of electrical standards for machine tools has been adopted by the machine tool industry, in accordance with specifications drawn up by the committee on electrical problems of the National Machine Tool Builders' Association. "Machine Tool Electrical Standards" is planned to relieve customers of the necessity for writing elaborate electrical specifications of their own, and to insure that the machine tools that they buy will be properly wired. There will also be the incidental advantage that assembly of machine tools will be expedited because it will no longer be necessary to make every machine tool a special wiring job to meet special specifications. Copies of the standard may be obtained from the National Machine Tool Builders' Association, Cleveland, Ohio, at $1.00 per copy.

Honors • • • •

D. R. Yarnall Receives 1941 Hoover Medal Award

D. R. Yarnall, co-founder and chief engineer, Yarnall-Waring Company, Chestnut Hill, Pa., was awarded the Hoover Medal, joint award of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, and AIEE, at the annual meeting of the American Society of Mechanical Engineers. The medal, presented this year for the fifth time, is awarded "by engineers to a fellow engineer for distinguished public service." Mr. Yarnall received the degree of mechanical engineer from the University of Pennsylvania in 1905, and after a few years as engineer for the Coatesville (Pa.) Boiler Works, and Stokes and Smith Company, he became vice-president and general manager of the Nelson Valve Company, Philadelphia, Pa., in 1912. He was also co-founder in 1912 of the Yarnall-Waring Company, and has been a member of the firm since that date. In 1920 he served as a member of the commission in Europe having charge of feeding German children, and in 1938 was sent to Vienna and to Berlin by the American Friends Service Committee, to aid refugees. He has served as a director of the United Engineering Trustees, and is a former vice-president of the Engineering Foundation, and a past president of the United Engineering Trustees. He is a member of the American Society of Mechanical Engineers and of the American Association for the Advancement of Science. The medal,

established in 1929 by gift of Conrad N. Lauer of Philadelphia, past-president of the American Society of Mechanical Engineers, has been previously awarded to former President Herbert Hoover (HM'29) whose civic and humanitarian achievements it was established to commemorate; to Ambrose Swasey (HM'28) founder of the Engineering Foundation; to John F. Stevens, chief engineer of the Panama Canal; and to Gano Dunn (A'91, F'12) president of the J. G. White Engineering Corporation, New York, N. Y., and past president and Edison Medalist of the AIEE.

One of the winners in the industrial class of the sixth annual Modern Plastics competition, held in November 1941, was this ratio adjuster for power transformer, designed and produced by General Electric Company

American Welding Society Awards Miller Medal

The Miller Memorial Medal, awarded by the American Welding Society for conspicuous contributions to the art and science of welding was presented to David Arnott, chief surveyor and vice-president, American Bureau of Shipping, New York, N. Y., at the annual meeting of the society. The medal was awarded to Mr. Arnott for his work in advancing the application of welding to ship construction. After studying naval architecture at the Royal Technical College, Glasgow, Scotland, Mr. Arnott served an apprenticeship in shipbuilding at the Fairfield Shipbuilding and Engineering Company, Ltd., Glasgow. In 1901 he was made a surveyor for the British Corporation for the Survey and Registry of Shipping, Glasgow, and in 1917 was appointed principal surveyor for the company in Canada. He came to New York in 1918 as deputy chief surveyor of the American Bureau of Shipping, was made chief surveyor in 1925, and chief surveyor and vice-president in 1938.

1941 Chemical Industry Medal Awarded to E. K. Bolton

The Chemical Industry Medal for 1941 has been presented to Dr. Elmer K. Bolton, chemical director of E. I. du Pont de Nemours and Company. The medal, which may be awarded annually for valuable application of chemical research to industry, was presented at a joint meeting of the American Section of the Society of Chemical Industry, the New York Section of the American Chemical Society, and the New York Section of the American Institute of Chemical Engineers.

Industry • • • •

Iowa University Opens Industrial Film Library. An industrial engineering film library of motion and time study films has been installed at the State University of Iowa. Films in the library, originally used in connection with courses in industrial engineering, will now be available to schools and industrial plants. The motion pictures, contrasting old methods with improved methods, show applications of motion study principles in offices and factories which result in better methods and lower costs. They will be installed by the department of visual instruction of the extension division of the university.

Charles A. Hoxie Dies. Charles A. Hoxie, retired, formerly with the General Electric Company, and inventor of the Hoxie sound-recording machine, died October 13, 1941. Born in Constable, N. Y., he was first engaged in development of an internal telephone system for cities, and was afterward associated with the New England Telephone Company. He joined the Hudson River Telephone Company in 1900 as wire chief. In 1912, he became an engineer for the General Electric Company, and there perfected a machine called a pallophotophone, which would record sound and film for motion pictures simultaneously. This type of recording process now is used by most of the motion-picture companies.

Granite Shaft Over "Time Capsule" Dedicated. A shaft of black granite, marking the spot 50 feet underground where the Westinghouse "time capsule" is buried, has been dedicated by the park department of New York City, at Flushing Meadow Park. Among the records and documents contained in the capsule is a copy of the 50th Anniversary (May 1934) issue of ELECTRICAL ENGINEERING in microfilm. Descriptions of the "time capsule" appeared in the October 1938 issue, page 430, and in the November 1940 issue, page 477.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

A Matrix Theorem

To the Editor:

From electric circuit theory a theorem in matrix algebra, believed to be new, is suggested and proved. The theorem resembles De Moivre's well-known theorem for complex numbers.

To most electrical engineers the utility of the general circuit constants is quite familiar. Thus if we have a four-terminal network with general circuit constants A_1, B_1, C_1, D_1 terminated in a second network with constants A_2, B_2, C_2, D_2 (figure 1), the constants A, B, C, D of the two networks in cascade considered as a single unit may be obtained by matrix multiplication as follows:

$$\begin{Vmatrix} A & B \\ C & D \end{Vmatrix} = \begin{Vmatrix} A_1 & B_1 \\ C_1 & D_1 \end{Vmatrix} \begin{Vmatrix} A_2 & B_2 \\ C_2 & D_2 \end{Vmatrix} \qquad (1)$$

Applying the above relation repeatedly to n identical networks with constants A_1, B_1, C_1, D_1 in cascade, we get the A, B, C, D of the whole from:

$$\begin{Vmatrix} A & B \\ C & D \end{Vmatrix} = \begin{Vmatrix} A_1 & B_1 \\ C_1 & D_1 \end{Vmatrix}^n \qquad (2)$$

In the special case of a uniform transmission line whose total series impedance and total shunt admittance are respectively Z and Y, the general circuit constants are:

$$\left.\begin{aligned} A_1 &= \cosh\theta \\ B_1 &= (Z/\theta)\sinh\theta \\ C_1 &= (\theta/Z)\sinh\theta \\ D_1 &= \cosh\theta \end{aligned}\right\} \qquad (3)$$

wherein

$$\theta = \sqrt{ZY}$$

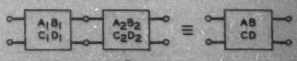


Figure 1

Suppose now n identical lines are connected in series. Then the total series impedance and the total shunt admittance become nZ and nY respectively while the quantity θ becomes also n times as large. The general circuit constants for n such lines in cascade are thus:

$$\left.\begin{aligned} A &= \cosh n\theta \\ B &= (Z/\theta)\sinh n\theta \\ C &= (\theta/Z)\sinh n\theta \\ D &= \cosh n\theta \end{aligned}\right\} \quad (4)$$

Hence by applying equation 2 we get the following matrix identity:

$$\begin{vmatrix} \cosh\theta & (Z/\theta)\sinh\theta \\ (\theta/Z)\sinh\theta & \cosh\theta \end{vmatrix}^n = \begin{vmatrix} \cosh n\theta & (Z/\theta)\sinh n\theta \\ (\theta/Z)\sinh n\theta & \cosh n\theta \end{vmatrix} \quad (5)$$

It is obvious from the physical nature of Z and Y that they may assume any value, real or complex, provided the real part is positive. As $\theta = \sqrt{ZY}$, its value is not limited in any way. Similarly let r be written in place of θ/Z to denote any number, real or complex, and multiply element of the left-hand matrix in equation 5 by r. We then get the following relation:

$$\begin{vmatrix} r\cosh\theta & \sinh\theta \\ r^2\sinh\theta & r\cosh\theta \end{vmatrix}^n = \begin{vmatrix} r^n\cosh n\theta & r^{n-1}\sinh n\theta \\ r^{n+1}\sinh n\theta & r^n\cosh n\theta \end{vmatrix} \quad (6)$$

or if we take $r = Z/\theta$, the relation assumes the alternate form:

$$\begin{vmatrix} r\cosh\theta & r^2\sinh\theta \\ \sinh\theta & r\cosh\theta \end{vmatrix}^n = \begin{vmatrix} r^n\cosh n\theta & r^{n+1}\sinh n\theta \\ r^{n-1}\sinh n\theta & r^n\cosh n\theta \end{vmatrix} \quad (7)$$

It will be noted that these relations have been suggested by physical considerations just like many other interesting relations in pure mathematics. It is not difficult to prove them rigorously. For this purpose we will use mathematical induction. Assume, therefore, that equation 6 is true for $n = k$ and multiply both sides by the matrix:

$$\begin{vmatrix} r\cosh\theta & \sinh\theta \\ r^2\sinh\theta & r\cosh\theta \end{vmatrix}$$

We thus obtain:

$$\begin{vmatrix} r\cosh\theta & \sinh\theta \\ r^2\sinh\theta & r\cosh\theta \end{vmatrix}^{k+1} = \begin{vmatrix} r\cosh\theta & \sinh\theta \\ r^2\sinh\theta & r\cosh\theta \end{vmatrix} \times \begin{vmatrix} r^k\cosh k\theta & r^{k-1}\sinh k\theta \\ r^{k+1}\sinh k\theta & r^k\cosh k\theta \end{vmatrix}$$

$$= \begin{vmatrix} r^{k+1}(\cosh\theta\cosh k\theta + \sinh\theta\sinh k\theta) & \\ r^{k+2}(\cosh k\theta\sinh\theta + \cosh\theta\sinh k\theta) & \\ r^k(\cosh\theta\sinh k\theta + \sinh\theta\cosh k\theta) & \\ r^{k+1}(\sinh\theta\sinh k\theta + \cosh\theta\cosh k\theta) & \end{vmatrix}$$

$$= \begin{vmatrix} r^{k+1}\cosh(k+1)\theta & r^k\sinh(k+1)\theta \\ r^{k+2}\sinh(k+1)\theta & r^{k+1}\cosh(k+1)\theta \end{vmatrix} \quad (8)$$

since

$$\cosh(k+1)\theta = \cosh\theta\cosh k\theta + \sinh\theta\sinh k\theta$$

and

$$\sinh(k+1)\theta = \sinh\theta\cosh k\theta + \sinh k\theta\cosh\theta$$

Now equation 8 shows that if equation 6 is true for $n = k$, then it is also true for $n = k+1$. As equation 6 is true for $n = 1$, it is therefore true for $n = 2, 3$, etc. Hence the relation is true for all positive integral values of n. Similarly we can establish the validity of equation 7. But, as

$$\begin{vmatrix} \cosh\theta & r^{-1}\sinh\theta \\ r\sinh\theta & \cosh\theta \end{vmatrix}^{-1} = \begin{vmatrix} \cosh\theta & -r\sinh\theta \\ -r^{-1}\sinh\theta & \cosh\theta \end{vmatrix} \quad (9)$$

and equation 7 is true for any value of θ or r, it is evident that equation 6 holds even when n is a negative integer. By thus permitting n to take any integral value, the two alternate forms equations 6 and 7 become only one.

The close similarity between equations 6 or 7 to De Moivre's well-known theorem for complex numbers,

$$(r\cos\phi + jr\sin\phi)^n = (r^n\cos n\phi + jr^n\sin n\phi)$$

may be noted. This resemblance can be made the more striking, if we let $\theta = j\phi$ and remember $\cosh j\phi = \cos\phi$ and $\sinh j\phi = j\times\sin\phi$, wherein $j = \sqrt{-1}$. Thus using circular instead of hyperbolic functions, our theorem becomes:

$$\begin{vmatrix} r\cos\phi & j\sin\phi \\ jr^2\sin\phi & r\cos\phi \end{vmatrix}^n = \begin{vmatrix} r^n\cos n\phi & jr^{n-1}\sin n\phi \\ jr^{n+1}\sin n\phi & r^n\cos n\phi \end{vmatrix} \quad (10)$$

A special case, possessing more symmetry, is to put $r = 1$. Then

$$\begin{vmatrix} \cos\phi & j\sin\phi \\ j\sin\phi & \cos\phi \end{vmatrix}^n = \begin{vmatrix} \cos n\phi & j\sin n\phi \\ j\sin n\phi & \cos n\phi \end{vmatrix} \quad (11)$$

a corollary of which is evidently

$$\begin{vmatrix} \cos n\phi & j\sin n\phi \\ j\sin n\phi & \cos n\phi \end{vmatrix} \begin{vmatrix} \cos m\phi & j\sin m\phi \\ j\sin m\phi & \cos m\phi \end{vmatrix} = \begin{vmatrix} \cos(m+n)\phi & j\sin(m+n)\phi \\ j\sin(m+n)\phi & \cos(m+n)\phi \end{vmatrix} \quad (12)$$

A. Pen Tung Sah (A'35, M'36)

(President, National University of Amoy, Changting, China)

Service-Factor Ratings

To the Editor:

I have seen the paper on "The Service Factor Rating of Arc-Welding Generators and Transformers," by R. C. Freeman and A. U. Welch on pages 137–41 of AIEE Transactions, volume 60, 1941 (April section) and I feel that I must send you a note to say how welcome it is. I happen to have been interested in its subject rather intimately for some months past, and I hope that the proposals now made will have their effect in establishing the sound principles they represent. If it were to come to a discussion, I would suggest that a duty-cycle standard of 60 per cent is unnecessarily high, and I should propose something much nearer the 40 per cent of the French rules (much of the evidence of your article, indeed, seems to me to support this); but that is not important at the moment. The main thing is to get the principles of one duty-cycle standard, one service-factor rating, and one set of temperature-rise limits established for all types of hand-welding equipment, including both generators and transformers, no matter what their enclosure or cooling-means may be.

You may be interested to know that thought is proceeding on the same general lines in some quarters over here. An article by J. W. Bayles, MSc. (Eng.), and an associate member of the Institution of Electrical Engineers (a good friend of mine), published in the *BEAMA Journal*, November 1940, treated the subject in outline in very much the same way, and arrived, in principle, at the same conclusions.

Thomas Carter (F'20)

(A. Reyrolle and Company, Ltd., Hebburn-on-Tyne, England)

(*Editor's Note:* See also pages 569–71 of this issue.)

Numerical Solution of Equations

To the Editor:

D. L. Waidelich's article on numerical solutions of equations (*EE, Oct. '41, p. 480–2*) is of some interest, although it is hard to see how Newton's method could be "not very generally known among engineers". Any respectable course in college algebra will include this.

Mr. Waidelich did not mention the "Graeffe method" of solving linear algebraic equations. This method is not as well known as Newton's or the iteration methods, but is much quicker when the degree of the equation is high. Also, a high degree of accuracy is easily obtained.

A very lucid exposition of this method is given by Kurtz and Corcoran in their "Introduction to Electrical Transients".

William M. Breazeale (A'31)

(Radiation Laboratory co-operating with National Defense Research Committee, Massachusetts Institute of Technology, Cambridge)

Copper Shortage

To the Editor:

The October issue of Electrical Engineering carries under the heading "Of Current Interest" an item on copper. I wonder if those in charge in Washington realize that the threatened copper shortage is brought about largely by their action.

If the price of copper is fixed at 12 cents per pound f.o.b. Naugatuck Valley, production is confined to those who can mine, smelt, refine, and lay down copper at this price without loss.

Colorado, Arizona, New Mexico are shot through with low-grade copper ore which would come into the market in quantity under a small increase in price, and elimination of the copper shortage is only a matter of allowing the price to rise to a point where supply equals demand. It is unfortunate that some of the Washington dreamers cannot see the light.

Plenty of copper at 14, 16, or 18 cents per pound would be much better than no copper at 12 cents, which seems to be the impending dilemma.

Frederick G. Strong (A'19, F'13)

(Wethersfield, Conn.)

New Books • • •

"Industrial-Commercial Electrical Reference." Under preparation for more than four years this 1,200-page reference volume by B. S. Lincoln (F'41) consulting engineer, has just been issued by the Electrical Modernization Bureau, representing a group of some 80 manufacturers of electrical equipment. The contents are based upon the wide experience of the author, who has been engaged as industrial consultant for many years, supplemented by selected information furnished by men in the electrical field who have rendered extensive, valuable advisory service to industrials for years. The book is intended to serve primarily electrical men in industrial plants, covering the entire field of industrial electrical operations from service entrance through utilization equipment. Each section devoted to service or utilization equipment is divided into "installation" and "operation" sections. "Installation" covers economic factors, selection of equipment, layout, application, and control; "operation" includes inspection, maintenance, testing, surveys, analysis of performance and operating costs, and correction of faulty operation. Sections are devoted to relations with manufacturers, industrial-plant managements, contractors, consultants, and utilities; industrial and professional associations; distribution systems; protection and control equipment; and various types of utilization equipment. Separate sections also cover such subjects as inspection, maintenance, testing, surveys, performance and cost analysis, power factor, and voltage correction. As an aid to proper installation of equipment, the book includes the complete National Electrical Code, the various sections being reproduced with the material to which they apply. The volume is liberally indexed and arranged so as to assist the industrial electrical man to find with the least possible delay the answers to problems demanding immediate solution. Purchasers of the book will receive a "supplementary service" consisting of new material to be issued periodically which will keep the subject matter continuously up to date. Published by Electrical Modernization Bureau, New York, N. Y.; approximately 1,200 pages, 300 illustrations, 300 tables; 9 by 11¼ inches, Fabrikoid; price $15, including supplementary service.

"Standard Handbook for Electrical Engineers." Seventh edition, 1941, revised and enlarged. The most recent edition of this electrical encyclopedia has been completely revised, to recognize shifts in order of importance of the branches of the electrical art, and to include new spheres of activity which have appeared in the eight years since the sixth edition was published. To facilitate handling and filing, and to provide a more legible book for reference, the format has been changed to one having larger overall dimensions, less bulk, and a larger type size for easier reading. Presentation of material has been based on the results of interviews with more than 100 electrical engineers, with the result that the handbook aims to answer the demand for an orderly compilation of the "working-tool information of electrical technology" which has been authenticated by research and experience, but is not generally accessible in a compact form. An attempt has also been made to meet a demand for terse condensation of abstract principles, without sacrifice of completeness, so that maximum space might be available for presentation of the accepted data of applied engineering, as given by practical experts. Most of the contributors are new, but have been selected for their authoritative standing, and for their ability to give an up-to-date presentation of the subject in which they are specialists. Changes include: expansion of the section on power-plant electrical equipment to embrace electrical equipment for the whole power system; new treatments of power transmission, electronics and radio, interior wiring, illumination, prime movers, and telephone; recognition of modern developments such as air conditioning, electricity in aviation and in the petroleum industry, lightning technology, high-voltage generators, and cyclotrons; and the expansion of the compilation of codes and standards. The index has been enlarged and elaborately cross-referenced. Edited by A. E. Knowlton (M'17, F'30) associate editor, *Electrical World*. McGraw-Hill Book Company, Inc., New York, 1941, 2303 pages, price $8.00.

"Family Expenditures in the United States," published by the National Resources Planning Board, presents a detailed statistical picture of how American families spend their incomes, based on a survey applying to the year 1935–36. The analysis of family spending and saving at different income levels includes a breakdown of expenditures into more than 90 items, with separate figures for farm, rural nonfarm, and urban families, and with comparative estimates for white and negro families, for five geographic regions, and for three sizes of family. The volume is the third of a series of reports on purchasing power and consumption requirements of the American people, the first two of which were "Consumer Incomes in the United States," and "Consumer Expenditures in the United States." The report shows that of the $41,000,000,000 spent for current consumption needs, less than nine per cent was spent for automobiles, household equipment, and other durable goods, and less than ten per cent for semidurable goods. Food and other perishable goods accounted for 47 per cent. Prepared by Dr. Hildegarde Kneeland and a technical staff. United States Government Printing Office, Washington, D. C., 1941, price 50 cents.

"An Introduction to the Operational Calculus." The purpose of this book is stated as being "to develop some of the methods of the operational calculus for the use of engineering undergraduates whose mathematical equipment is necessarily limited, and for practicing engineers whose mathematical equipment has become rusty through disuse." The material is developed gradually from known mathematical processes to newer ideas and methods, with the first part of the book containing a review of the classical methods of solving linear differential equations with constant coefficients. As opposed to the usual treatment of these subjects, this book makes use of the notation and nomenclature of the operational calculus. The operational calculus as developed in this book is merely a shorthand method of solving certain types of differential equations. By Walter J. Seeley, professor of electrical engineering, Duke University. International Textbook Company, Scranton, Pa., 1941, 167 pages.

"The Engineering Profession." This book describes qualifications and duties of the professional engineer, and his habit of mind. It thus aims to serve as a vocational guide to the young man in his choice of a profession, furnishing him with objective data for forming his own picture of engineering. It should also be of use to the vocational counselor who may be asked to supply information regarding the profession. Points of technology are discussed only by way of illustration. Contents of the books include: fields and functions of engineering; descriptions of the specialized fields of civil, mining, mechanical, electrical, and chemical engineering, and others; the method of engineering and application of this method; vocational guidance in engineering, and the education of the engineer; and requirements for admission to membership in engineering societies. By T. J. Hoover, dean, school of engineering, Stanford University, and J. C. L. Fish, emeritus professor of civil engineering, Stanford University. Stanford University Press, Stanford University, Calif., 1941, 441 pages, price $5.00.

"Electrical Wiring Specifications." This book is a review of design and specification procedure for electrical wiring jobs, presented as a working guide for all concerned with designing wiring installations, laying out wiring systems, and developing specifications for any given job, and containing rules for carrying out these procedures in compliance with the National Electrical Code. It is an authoritative book on a subject of wide importance. Edited by Earl Whitehorne. McGraw-Hill Book Company, Inc., New York and London, 1941, 181 pages, price $2.50.

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

PRINCIPLES OF MAGNAFLUX INSPECTION. By F. B. Doane. Magnaflux Corporation, Chicago, 1940. 133 pages, illustrated, 9½ by 6 inches, cloth, $2.50. A description of magnaflux inspection methods, covering equipment, processes, the inspection medium, detectable defects, demagnetization, and the evaluation of indications. There is a separate chapter on weld inspection, and basic physical principles also are discussed briefly. Bibliography.

THE THEORY OF RATE PROCESSES. By S. Glasstone, K. J. Laidler, and H. Eyring. McGraw-Hill Book Company, New York and London, 1941. 611 pages, diagrams, etc., 9 by 6 inches, cloth, $6.00. This book describes the development and application of a general theory of the kinetics of physical and chemical processes, usually known as the "theory of absolute reaction rates". The fundamental bases are explained, and homogeneous and heterogeneous gas reactions, reactions in solution, viscosity, diffusion, and electrochemical phenomena are considered in terms of the theory.

ATM (Archiv für technisches Messen), Lfg. 119, May 1941. R. Oldenbourg, Munich and Berlin, pages T63–77, F3; illustrated, 12 by 8½ inches, paper, 1.50 rm. each. This monthly publication contains classified articles upon various types of apparatus and methods of technical measurement.

There are also descriptions of specific instruments manufactured by German companies.

ELECTRICAL ENGINEERING FUNDAMENTALS. By G. F. Corcoran and E. B. Kurtz. John Wiley and Sons, New York, 1941. 450 pp., diagrams, etc., 9 by 6 inches, cloth, $4.00. The subject matter presented in this textbook is intended as first course material to prepare electrical engineering students for specialized courses. Special emphasis has been given to the arrangement and explanation of basic principles and concepts, although certain chapters deal with more advanced topics.

ENGINEERING DESCRIPTIVE GEOMETRY AND DRAWING. By F. W. Bartlett and T. W. Johnson. John Wiley and Sons, New York; Chapman and Hall, Ltd., London, 1941. 372 pages, illustrated, cloth $4.50. This comprehensive textbook, developed for use at the United States Naval Academy, consists of three parts: I. Line drawing, which is chiefly concerned with the manner of handling the instruments; II. Engineering descriptive geometry, which deals with the rules of orthographic projection applied to simple geometrical shapes; and III. Engineering drawing, which deals with the application of the general principles of drawing to engineering purposes with emphasis on detail drawing.

ENGINEERING ENCYCLOPEDIA. Two volumes. Edited by F. D. Jones. Industrial Press, New York, 1941. 1431 pages, diagrams, etc., 9½ by 6 inches, fabrikoid, $8.00. This two-volume reference work supplies practical information such as the various important mechanical laws, rules, and principles; physical properties and compositions of materials used in engineering practice; and the characteristic features and functions of different types of machine tools and other equipment. The 4,000 topics included are alphabetically arranged and cross-indexed, and have been selected for their usefulness in the mechanical industries.

INDEX TO THE LITERATURE ON SPECTROCHEMICAL ANALYSIS, 1920–1939. Second edition. By W. F. Meggers and B. F. Scribner; publication sponsored by Committee E-2 on spectrographic analysis of the American Society for Testing Materials, Philadelphia, 1941. 104 pages, 9 by 6 inches, paper, $1.00. Nearly 1,500 references are contained in this second edition of an index which appeared originally in 1937. This constitutes a 50 per cent increase in the literature from 1920 to 1939 is covered chronologically, with the authors alphabetically arranged within each calendar year. Detailed subject index.

THE SECOND YEARBOOK OF RESEARCH AND STATISTICAL METHODOLOGY BOOKS AND REVIEWS. Edited by O. K. Buros. Gryphon Press, Highland Park, N. J., 1941. 344 pages, 11 by 8½ inches, cloth, $5.00. This book consists of carefully selected critical reviews of books dealing with statistical methods and techniques in a variety of fields. Three hundred and fifty-nine books published since 1932 are included, providing a list of the latest publications on the subject, and also the means for evaluating them. Indexed by title, subject, and reviewer.

TABLE OF NATURAL LOGARITHMS. Volume 1. Logarithms of the Integers from 1 to 50,000. Prepared by the Federal Works Agency, Work Projects Administration for the City of New York; conducted under the sponsorship of and for sale by the National Bureau of Standards, Washington, 1941. 501 pages, tables, 11 by 8 inches, cloth, $2.00, payment in advance. Continuing the series of mathematical tables being compiled by the Work Projects Administration, this book constitutes volume 1 of a projected four-volume table of natural logarithms. The natural logarithms are given here to 16 decimal places for the integers from 1 to 50,000. Succeeding volumes will carry to 100,000 and cover the range from 0 to 10 at intervals of 0.0001.

PRACTICAL SOLUTION OF TORSIONAL VIBRATION PROBLEMS. Volume 2. By W. K. Wilson. Second edition. John Wiley and Sons, New York, 1941. 694 pages, illustrated, 9 by 5½ inches, cloth, $8.50. Owing to the extensive revision and enlargement of the new edition of this work, it was divided into two volumes. The second volume deals with the determination and measurement of stresses owing to torsional vibration, the analysis of torsiograph records, damping devices and rotating-pendulum vibration absorbers, and the dynamic characteristics of electrical-mechanical direct-coupled systems. Practical examples are worked out, and an appendix contains a discussion of harmonic analysis, a bibliography, and a selected list of British patents.

QUARZDRUCKMESSGERÄTE HÖHER EIGENFREQUENZ, Schwingungseigenschaften und Abhilfe gegen die Störung durch Massenkräfte. By W. Gohlke. VDI Forschungsheft 407, March-April, 1941. VDI-Verlag, Berlin. 1–25 pages, illustrated, 12 by 8 inches, paper, 5 rm. The two articles contained in this research publication on piezoelectric measuring devices of high natural frequency deal respectively with their oscillatory properties and with the disturbing effects of inertial forces on readings.

SYMPOSIUM ON COLOR. Its Specification and Use in Evaluating the Appearance of Materials. Jointly sponsored by the American Society for Testing Materials and the Inter-Society Color Council. Washington Spring Meeting, American Society for Testing Materials, Philadelphia, 1941. 79 pages, illustrated, 9½ by 6 inches, cloth, $1.25; paper, $1.00. Six technical papers, affording a broad view of the various aspects of color research, are contained in this symposium. The following list of titles indicates the scope: introduction to color; color specifications of transparent materials; hiding power and opacity; color standards for opaque materials; spectrophotometry and color evaluation; photoelectric tristimulus colorimetry.

TABLES OF PROBABILITY FUNCTIONS Volume 1. Prepared by the Federal Works Agency, Work Projects Administration for the City of New York; conducted under the sponsorship of and for sale by the National Bureau of Standards, Washington, 1941. 302 pages, tables, 11 by 8 inches, cloth, $2.00, payment in advance. The present volume, which is the seventh in the series of mathematical tables now under preparation extends the range of all existing tables of the error function and provides a somewhat smaller table of e^{-x^2}. As in the volumes of the series, provision has been made to facilitate both direct and inverse interpolation. Entries given to 15 decimal places.

ELEMENTS OF ENGINEERING THERMODYNAMICS. By J. A. Moyer, J. P. Calderwood, A. A. Potter. Sixth edition, rewritten. John Wiley and Sons, New York; Chapman and Hall, London, 1941. 417 pages, diagrams, 9 by 6 inches, cloth, $2.50. As in the present edition, as in the previous ones, this book is designed to stress the fundamental principles of engineering thermodynamics as a foundation for the more advanced and practical applications of the theory. It is intended particularly for use in technical colleges having special courses in advanced thermodynamics, steam turbines, internal combustion engines, heating, refrigeration and other applications of thermodynamics.

TRANE AIR-CONDITIONING MANUAL. Revised edition. The Trane Company, La Crosse, Wis., 1941. 376 pages, illustrated, 11½ by 8½ inches, $5.00. This publication is primarily concerned with the application of the fundamental facts of engineering to the design of air-conditioning systems. Heat and its transmission, physical comfort, air properties and supply, psychrometry, refrigeration and ventilation processes, the functions of water in air conditioning, and a chapter on ducts and fans, new in this edition, are covered in this comprehensive treatment of the subject. Diagrams, tables, problems and numerical examples.

FUNDAMENTALS OF VACUUM TUBES. By A. V. Eastman. Second edition. McGraw-Hill Book Company, New York and London, 1941. 583 pages, illustrations, 9½ by 6 inches, cloth, $4.50. The aim in this work has been to combine in a single text the basic theory underlying the operation of all types of modern vacuum tubes with descriptions of their more common applications in communications and industry. Descriptions and mathematical analyses of the phenomena under consideration are given. Revised and rearranged.

NUCLEAR PHYSICS. (University of Pennsylvania Bicentennial Conference.) By E. Fermi and others. University of Pennsylvania Press, Philadelphia, 1941. 72 pages, diagrams, etc., 9 by 6 inches, paper, $0.75. This pamphlet contains six papers presented at a conference on nuclear physics held in connection with the bicentenary of the University of Pennsylvania.

THROUGH ENGINEERING EYES. Science Selections from Literature. By A. R. Cullimore, revised by H. Grenville and I. Pi. Fitz-Gerald. Pitman Publishing Corporation, New York and Chicago, 1941. 166 pages, illustrated, 7½ by 5½ inches, linen, $1.00. Presented with the aim of "picturing the development of science and engineering", this volume consists of selections from a variety of books, ancient and modern, written by engineers, scientists, poets, essayists, and philosophers. Each is included because it has "a direct bearing on engineering".

THE THEORY AND APPLICATIONS OF HARMONIC INTEGRALS. By W. V. D. Hodge. University Press, Cambridge, England; Macmillan Company, New York, 1941. 281 pages, tables, 9 by 5½ inches, cloth, $4.50. This book is a study of certain integrals defined in a type of space, locally that of classical Riemannian geometry, which is of importance in various branches of mathematics. Topics covered are: Riemannian manifolds; integrals and their periods; harmonic integrals; applications to algebraic varieties; and applications to the theory of continuous groups.

THE TESTING AND INSPECTION OF ENGINEERING MATERIALS. By H. E. Davis, G. E. Troxell, and C. T. Wiskocil. Preliminary edition for Engineering Defense Training Courses. McGraw-Hill Book Company, New York and London, 1941. 372 pages, illustrated, 10 by 7 inches, cloth, $3.50. In view of the increasing importance of quality control in production and its dependence upon tests and inspection, it is the aim of the authors to provide in this book a general treatment of the problems of testing, with specific reference to the mechanical testing of engineering materials, and to establish the principles for the inspection of these materials. Methods of conducting common tests, applicable to most ordinary apparatus, are described in the second section of the book.

TABLE OF NATURAL LOGARITHMS. Volume 2. Logarithms of the Integers from 50,000 to 100,000. Prepared by the Federal Works Agency, Work Projects Administration for the City of New York; conducted under the sponsorship of and for sale by the National Bureau of Standards, Washington, D. C., 1941. 501 pages, tables, 11 by 8 inches, cloth, $2.00, payment in advance. The second volume of this table continues it for the integers from 50,000 to 100,000. Values are given to sixteen decimal places.

THE RUNNING AND MAINTENANCE OF MARINE MACHINERY. Institute of Marine Engineers, London. Second edition. Engineers' Book Shop, New York, 1941. 164 pages, illustrated, 10 by 7 inches, cloth, $2.50. A practical work, prepared for junior members of the Institute of Marine Engineers, intended as a guide for those entering upon a sea-going career. Steam reciprocating engines and turbines, boilers, diesel engines, electrical and refrigerating machinery, pumping arrangements, and steering gears are discussed. A list of books is included.

PRACTICAL SHIP PRODUCTION. By A. W. Carmichael. Second edition. McGraw-Hill Book Company, New York and London, 1941. 283 pages, illustrated, 9½ by 6½ inches, cloth, $3.00. The present issue of this shipbuilding is responsible for the revision of this text, which appeared originally in 1919. The book is intended particularly for engineers and technical men who are transferring their activities from other fields to marine engineering and naval architecture. The treatment is practical, rather than theoretical, and concerned with construction, rather than design. The new edition has been partly rewritten, especially the section on electric welding.

MOTION STUDY. By H. C. Sampter. Pitman Publishing Company, New York and Chicago, 1941. 152 pages, illustrated, 9½ by 6 inches, cloth, $1.75. The principles of motion study, as distinct from time study, are clearly presented. Motion symbols are explained, the basic laws and principles for motion economy discussed, and flow process charts to eliminate the study of superfluous operations in a series or complete process.

MODERN MARINE ELECTRICITY. By P. de W. Smith. Cornell Maritime Press, New York, 1941. 279 pages, illustrated, 7½ by 5 inches, cloth, $2.50. This handbook is intended to provide the operating marine electrician with a practical guide to the electrical equipment of the modern ship and to its maintenance.

ELECTRONICS. By J. Millman and S. Seely. McGraw-Hill Book Company, New York and London, 1941. 443 pages, illustrated, 9 by 6 inches, cloth, $5.00. This textbook is intended to provide a development of basic electronic principles with applications to many problems in electrical engineering and physics. It contains the physical theory of electronics and the theory of operation of electronic devices, gives attention to material of present-day commercial importance, and includes both detailed illustrative problems and groups of problems to be worked.

ELECTRICITY APPLIED TO MARINE ENGINEERING. By W. Laws. Institute of Marine Engineers, London; England Book Shop, New York, 1940. 276 pages, diagrams, etc., 7½ by 5 inches, cloth, $2.00. A clear, simple presentation of the fundamental principles of electricity, with special emphasis upon their application to ships. The text is intended for young engineers without much mathematical or technical background, who are preparing for British Board of Trade Certificate examinations, and is based upon articles published in the *Transactions* of the Institute of Marine Engineers.

THE BELL TELEPHONE SYSTEM. By A. W. Page. Harper and Brothers, Publishers, New York and London, 1941. 248 pages, illustrated, 9 by 6 inches, cloth, $2.00. This is a description of the operating policies of the American Telephone and Telegraph Company and its constituent companies, written by the vice-president in charge of public relations. Problems of research, technology, wages, rates and service, relations with the government, and finance are considered, and the methods and achievements of the organization set forth. Much hitherto scattered information is brought together in convenient form.

TEMPERATURE MEASUREMENT AND CONTROL. By R. L. Weber. Blakiston Company, Philadelphia, 1941. 430 pages, illustrated, 9 by 6 inches, cloth, $4.00. This textbook is a revision of a preliminary edition published under the title, "Temperature Measurement". Based upon a course offered to Juniors at Pennsylvania State College, it outlines "an experimental study of the methods of temperature measurement with the theoretical principles necessary for their appreciation, intelligent use and extension".

Transactions Section

Preprint of Corresponding Pages From the Current Annual Transactions Volume

Any discussion of these papers will appear in the December 1941 "Supplement to Electrical Engineering—Transactions Section"

Field Testing of Generator Insulation

EEI SUBJECT COMMITTEE ON GENERATOR INSULATION AND TESTING

I—Introduction

NEED for a practical as well as a reliable nondestructive test that will determine the condition of generator insulation has long been recognized by the industry. Simple methods now in general use, the high voltage proof test and the insulation resistance test, do not accurately or positively disclose the overall condition of windings, indicate the degree of deterioration, or necessarily locate weak spots. This lack of suitable insulation tests has been emphasized recently by the return to service of a number of machines either after long shutdown periods during the depression years or from standby service to low pressure elements used in connection with topping units; in these cases knowledge of insulation condition is vital.

As a result of this situation the Edison Electric Institute electrical equipment committee undertook active work on the problem in 1935.[1] In 1937 a special subject committee was appointed on "Generator Insulation and Testing," with the ultimate object of developing a reliable test procedure for determining the condition of generator insulation. The investigation has been carried out by various member companies of the EEI and others in the industry interested in the problem, under the guidance of the subject committee. Close contact has also been maintained with the manufacturers who have made many valuable suggestions, assisted in testing, and given aid in analyzing data.

The study is by no means complete and this paper should not be construed as a final report with definite conclusions, but rather as a progress report on an investigation still under way.

Paper 41-17, recommended by the AIEE standards committee, and presented at the AIEE winter convention, Philadelphia, Pa., January 27-31, 1941. Manuscript submitted November 6, 1940; made available for preprinting December 6, 1940.

Personnel of EEI subject committee on generator insulation and testing: C. M. Gilt and B. Van Ness, Jr., subject sponsors; R. L. Webb, chairman; J. B. Allen, E. F. Dissmeyer, O. E. Fawcett, A. P. Hayward, R. J. Woodrow.

The subject committee wishes to acknowledge the assistance and co-operation rendered in this work by EEI member companies and engineers, by other engineers and utility companies, and by the manufacturers.

1. For all numbered references, see list at end of paper.

II—Present Status of Insulation Testing

Present testing practice in this country was surveyed in 1938, revealing a wide variation in testing methods and procedure. High voltage proof testing which consists merely of the stressing of the insulation by the application of an alternating potential according to the rules in the AIEE Standards is generally used for acceptance tests for new and repaired machines. There is no general agreement as to advisability of routine proof testing nor magnitude nor frequency when such tests are applied to machines in service. Insulation resistance testing is a common practice though generally a definite routine is not followed. In the past the procedure often has consisted of a "crank and read" type of measurement. Today, increasing recognition is being given the fact that insulation resistance values may be misleading unless careful account is taken of the many factors which may affect the results. No definite practice seems to be established regarding other methods of test, such as high voltage d-c resistance, dielectric loss or power factor tests.

Comparatively few operating companies maintain regular schedules of periodic insulation testing, from which records may be obtained to serve as a guide of the progressive condition of the insulation. Such special tests as are made are carried out usually after a machine winding has been repaired or an inspection indicates it to be in questionable condition.

Foreign practice in this respect also indicates a lack of uniformity. In some countries, notably Germany and Switzerland, experiments have been made with dielectric loss measurements, and it is felt there that this type of measurement has some promise of value as an index of changing insulation condition. A few experiments have made use of a recording instrument giving a curve of dielectric losses versus time during machine operation. It has been suggested that this method may give a definite index of changing conditions within the insulation. The method has not received broad use.

III—Scope of Work

Originally it was the objective of the subject committee to conduct destructive and nondestructive tests on insulation of machines about to be scrapped, rewound, or repaired and to develop from these a workable nondestructive method of determining insulation condition. Valuable information has been obtained from these tests but inasmuch as many of the data consist of "spot" readings taken under a variety of conditions, it has not been possible to correlate all of the data nor to draw definite conclusions. Real need for periodic and standardized measurements has become apparent. The scope of the investigation has been broadened to include and encourage the collection of periodic nondestructive test data on machines in service. By this means information is being accumulated on all classes of insulation, from the old to the new.

Insulation characteristics of both armature and field windings are undergoing investigation. Table I summarizes the machines tested or under test. The machine ratings vary from 1,500 kva, 2,700 volts to 200,000 kva, 16,500 volts.

Table I

Type of Test	Number of Machines
Insulation resistance	106
Power factor of insulation	27
Ionization	8
Voltage strength a-c	21
Voltage strength a-c versus d-c	6*

* Includes 2-2.3 kv motors.

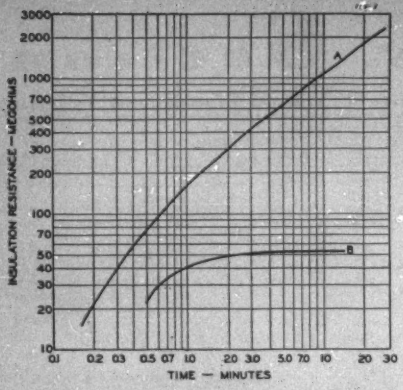


Figure 1. Armature-winding insulation resistance versus time

A—20,000-kva single-barrel generator, 16.5 kv, 60 cycles, 1,800 rpm (insulation dry)

B—18,750-kva single-barrel generator, 13.2 kv, 60 cycles, 1,800 rpm (insulation moist)

The subject committee, recognizing the need for uniform practice in insulation testing, has prepared a guide to be used in making such tests. Copies of this are available to the industry through EEI headquarters.

IV—D-C Insulation Resistance

Although d-c insulation resistance is among the most commonly used methods for testing the insulation of electrical apparatus, records obtained have been baffling of interpretation, and the factors which affect the results are to some extent unknown and often unappreciated. The fundamental that different types of insulating materials may have different volume resistances is obvious; but there are other variables which affect successive tests on a given piece of apparatus and cause widely varying results.

Tests have been directed to establish the manner in which the insulation resistance varies with

(*a*). Differences in insulation materials and structures
(*b*). Duration of voltage application
(*c*). Existing charge in windings
(*d*). Insulation temperature
(*e*). Test voltage magnitude
(*f*). Insulation moisture content
(*g*). Previous operating condition of the generator
(*h*). Various types of winding damage or deterioration

These investigations have confirmed findings obtained in similar experiments made by others and have gone somewhat further in extending the limits to which such tests have been conducted in the field.

Instruments

Experiments made so far have indicated that any one of several types of test instruments will give satisfactory insulation resistance results. Commercial forms of insulation resistance testers perform satisfactorily provided they are calibrated periodically and tested to assure their voltage output is proper. The maximum voltage at which measurements have been made with these instruments is 5,000 volts, d-c. Motor driven devices or other constant voltage generators are necessary for taking long time insulation resistance curves. Hand operated units may be used for short time readings.

The voltmeter method may be used with fair accuracy if the insulation resistance is less than 10 megohms. To insure accuracy of readings a high resistance voltmeter should be used.

Considerable success has been attained with electronic rectifier sets having d-c outputs from 100 to 5,000 volts and with dry cell battery sets up to 1,500 volts. These use a voltmeter and a microammeter for measurements which permit calculation of insulation resistance. They must be carefully shielded and guarded.

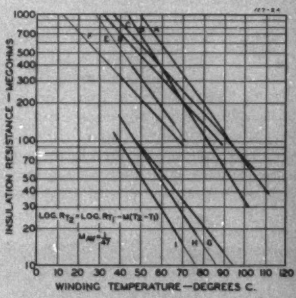
Higher voltages may be obtained from Kenotron test sets. Tests may be carried to any reasonable limit of voltage with this type of equipment, though 5,000 volts appears to be the present limit for sets portable by hand. In all rectifier sets it is essential that a steady supply of voltage be available to prevent fluctuation in charging current to the generator winding capacitance, an automatic voltage regulator being used if necessary.

Where protective resistors are used in test instruments their effect on the voltage magnitude applied to the insulation should be carefully taken into account.

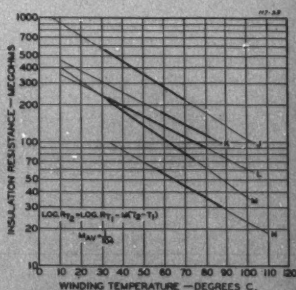
Duration of Voltage Application

While many insulation resistance measurements have been taken by the "crank and read" method, Wieseman[3] and others have shown that the insulation resistance of a winding varies with duration of voltage application. Insulation resistance of a dry winding in good condition may continue to increase for as long as a day or more with the test voltage applied continuously at a steady value. Normally an approximately final value, which is termed "apparent insulation resistance" may be reached after 10 to 15 minutes. Insulation resistance after 30 seconds to 60 seconds may be as little as 10 per cent to 20 per cent of the 15-minute reading.

In figure 1 insulation resistance versus time curves, commonly referred to as dielectric absorption curves, are shown for different conditions of generator insulation. Curve *A* is a good example of the effects of "bone dry" and clean insulation on the final value of insulation resistance and on the shape of the dielectric absorption curve. This curve represents an unusually high insulation resistance for a machine whose rating is 200,000 kva, 16,500 volts, in one stator winding. Curve *B* was taken on an 18,750-kva, 13,200-



Family having more common slope. Data taken at 500 to 20,000 volts after ten minutes



Family having lowest slopes. Data taken at 1,000 to 8,000 volts after one to ten minutes

Figure 2. Insulation resistance versus temperature

volt generator which had been exposed to varying degrees of atmospheric humidity for several years. Considering size alone this smaller unit would be expected to have a higher insulation resistance than the larger unit. However, the insulation conditions are such that the reverse is the case. Leakage resistance effects predominate and the curve flattens rapidly between the 30-second and the 3-minute readings.

Information contained in curves of this nature discloses the reason for at least one difficulty in past attempts to correlate insulation resistance readings, for it is obvious that "spot readings" made without regard to definite time of voltage application can give widely varying results.

Many dielectric absorption curves have been collected. While it is believed that these data give information as to dryness and cleanliness of winding, spot curves have not disclosed a positive relation between insulation resistance and insulation condition. Therefore, periodic curves are being taken and the behavior of the dielectric absorption factor over a long period is being observed and analyzed.

Effect of Existing Charge on Winding

Comparative values of winding insulation resistance are markedly affected by residual charges retained in a winding. For this reason windings should be grounded and discharged for at least ten minutes before applying insulation resistance tests.

Insulation Temperature

Tests have indicated that the insulation resistance of windings is affected greatly by temperature. The most marked effect occurs in class *A* windings but even in class *B* insulation structures, the insulation resistance may vary as much as 10 to 1 for a winding temperature change from approximately 25 degrees centigrade to 75 degrees centigrade, the insulation resistance being lower at the higher temperature.

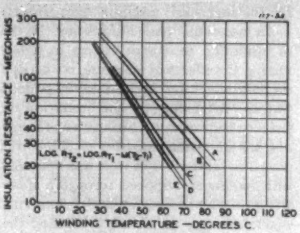
It is desirable that insulation resistance readings be taken at temperatures as close to 75 degrees centigrade as possible, to secure an indication of resistance at operating temperatures, eliminating the effect of humidity and requiring minimum temperature correction.

Figure 2 gives the results of field tests undertaken with the objective of establishing factors which will permit readings taken at one temperature to be transferred to a lower or higher temperature. The results so far indicate two families of curves, with similar characteristics of insulation resistance versus temperature in each group. The curves may be represented by the formula:

$$\log R_{t_2} = \log R_{t_1} - M(t_2 - t_1)$$

where R_{t_2} and t_2 are the unknown resistance and temperature at which the resistance is desired, R_{t_1} and t_1 are the measured resistance and the related winding temperature and M is a constant equal to the reciprocal of change in temperature for log $R=1$. Insulation resistance doubles for each 14 degree centigrade reduction in winding temperature for the curve whose $M=1/_{42}$, and doubles for each 31 degree centigrade reduction for the curve whose $M=1/_{104}$.

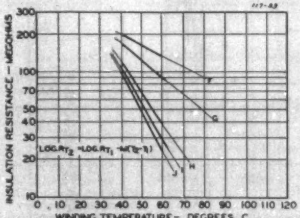
Although it might be assumed that the two families of curves bear definite relation to insulation class, this is not the case. Machines with both class *A* and class *B* windings appear in each group.



68,750-kva turbogenerator, 13.2 kv, 60 cycles, 1,800 rpm

Data taken following acceptance test run

A Insulation resistance at 10 min.—$M=1/_{43}$
B Insulation resistance at 4 min.—$M=1/_{50}$
C Insulation resistance at 1 min.—$M=1/_{41}$
D Insulation resistance at 30 sec.—$M=1/_{32}$
E Insulation resistance at 15 sec.—$M=1/_{28}$
Avg.—$M=1/_{44}$



Data taken following about two years of base-load service

F Insulation resistance at 10 min.—$M=1/_{118}$
G Insulation resistance at 4 min.—$M=1/_{74}$
H Insulation resistance at 1 min.—$M=1/_{41}$
I Insulation resistance at 30 sec.—$M=1/_{33}$
J Insulation resistance at 15 sec.—$M=1/_{24}$
Avg.—$M=1/_{60}$

Figure 3. Insulation resistance versus temperature for different periods of voltage application

Operating conditions apparently have a large effect on these characteristics, for data indicate that even after years of operation changes in the value of M for a given machine may occur from year to year. This is evident from figure 3 in which the curves having an average value for $M=1/_{44}$ were taken in 1938 shortly after a new generator was placed in service. The curves having an average value for $M=1/_{60}$ were taken on this same machine approximately two years later. The machine had been operated about 72 per cent of the elapsed time at an average of 95 per cent of rated capacity and had been run for several days, well loaded, before the last test. It is apparent, therefore that the value of M may vary for a given machine but it is not known definitely whether this variation is due to differences in moisture or volatile matter content in the insulation, or whether it is due to some aging or curing action which has been under way during the many continuous hours of high load operation. It is believed that moisture is the most likely cause of the variation.

While extrapolation of the curves of figure 3 appears to meet in a point at low temperatures other data indicate parallelism or a meeting at high temperatures. The reason for and meaning of these variations are not known.

No definite formula applicable to all machines, or even to the same machine under various conditions, can be given at this time for the relation of insulation resistance to temperature. Two readings taken at the same date on a machine will establish a curve for that machine for a definite condition of the insulation. A change in slope of an insulation resistance-temperature curve indicates a change in the insulation condition.

Effect of Moisture Content

Accurate insulation resistance data are very useful in determining the progress of drying machine insulation. It is customary to dry a machine until the insulation resistance readings at constant temperature approach a constant value when plotted with regard to time. When drying out, the attainment of a constant insulation resistance at a constant temperature is a better indication of dryness than is the attainment of some previously selected value.

Figure 4 indicates the variation of insulation resistance of a new turbo-generator whose winding is being dried. Each point of insulation resistance was taken after ten minutes application of test voltage. The insulation resistance dropped rapidly as the winding temperature in-

creased and then recovered as the moisture was driven from the insulation. When the test was terminated, the insulation resistance rose rapidly as the winding temperature decreased.

Figure 5 gives another method of plotting similar data as taken on the initial dry-out run of a 37,500-kva water-wheel generator and illustrates the value of the one- and ten-minute readings in obtaining a clear picture of the conditions during machine dry-out. It will be noted that as the run progressed the separation between the curves increased, indicating an effective drying of the insulation and the resulting increase of absorption effect in the dielectric.

by the increased machine temperature.

An interesting case, illustrating the use of insulation resistance curves in determining the effects of moisture, concerns a machine which had been subjected to flood waters. After dry-out, the insulation resistance increased to a satisfactory though not a high value and the machine was placed in service. The unit was operated with cooling air supplied through a spray system equipped with baffles for removing water from the air before it reached the generator. Later, after fairly continuous service, the generator was found to have low insulation resistance. The cooling air was suspected of carrying moisture into the machine and preventing thorough

Effect of Test-Voltage Magnitude

Insulation resistance measurements at 75 degrees centigrade of dry insulation in good condition will be affected very little by wide variations in test voltage. The effect appears to increase somewhat at lower temperatures as will be noted on figure 7. Windings having high leakage due to moisture or dirt, or other types of deterioration, may show a more pronounced reduction in insulation resistance as the test voltage is increased.

Results of complete tests on two machines, have indicated there may be some merit in comparisons between insulation resistance measurements at two different d-c voltages, at the same winding tem-

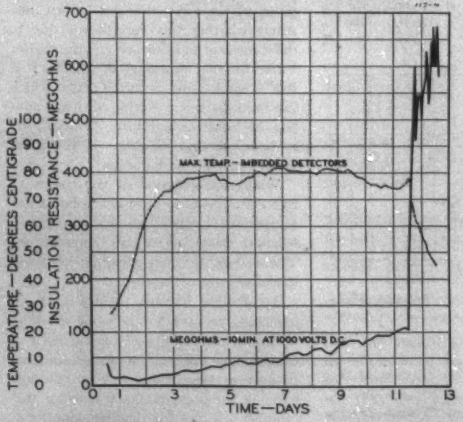


Figure 4. Change in ten-minute insulation resistance with time during generator dry-out

35,300-kva turbogenerator, 13.8 kv, 60 cycles, 1,800 rpm

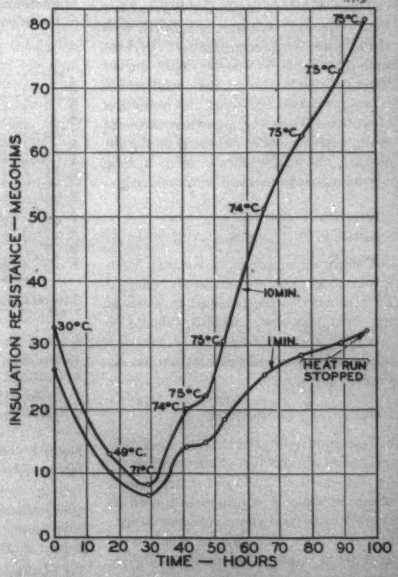


Figure 5 (right). Change in one-minute and ten-minute insulation resistance with time during generator dry-out

37,500-kva hydrogenerator, 13.3 kv, 25 cycles, 100 rpm

The degree of moisture content in the outer layers of generator winding insulation has a very marked effect on the insulation resistance. A machine which has been running regularly will generally have a much higher insulation resistance at room temperature than the same machine after being idle for several weeks in a humid atmosphere. A relatively low insulation resistance resulting from exposure to moist air does not necessarily mean that the insulation is inferior or that the machine is not safe for operation. If the insulation resistance is still reasonably high for the machine in question as shown by reference to periodic test data it may be returned to service and the moisture will be driven from its windings

drying. The unit was operated under test load for two hours using relatively dry turbine room air for generator cooling to learn of its effect on insulation resistance. Curves *A* and *B* of figure 6 show the insulation resistance results before and after this change in cooling air. As a result of these tests the unit, and several others in the same plant were equipped with surface coolers and a closed ventilating system, with improvement in insulation resistance as shown by curve *C* of figure 6.

Spray type air washers have not caused similar trouble at certain other locations where the same type of tests were made on generators whose windings had not been submerged.

perature. A 25,000-kw generator winding section was given a dielectric absorption test at 2.5 kv and at 15 kv d-c. The coils were then punctured on a 60-cycle high potential test and the insulation resistance values at the two voltages were again taken. The first test gave a ratio of approximately 2 to 1 with the 2,500-volt measurement being higher. The second test gave an insulation resistance ratio of approximately 6 to 1 after the insulation had been punctured. This test was repeated on another coil group and the ratio changed from approximately 2 to 1 to a ratio of approximately 4½ to 1.

The stator winding of a 30,000-kva synchronous condenser was found in very

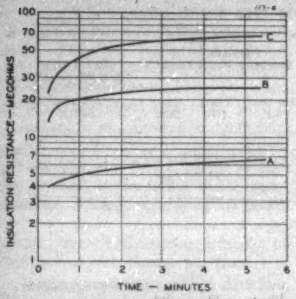


Figure 6. Armature-winding insulation resistance versus time

25,000-kva generator, 13.2 kv, 60 cycles, 1,800 rpm

Tests made at 500 and 1,000 volts d-c. Winding temperature—74 degrees centigrade

A—After using a water-spray air washer. Cooling air humidity—78 per cent

B—After using turbine-room air at approximately 38 per cent humidity during a two-hour load run made immediately after test *A*

C—After using a closed ventilation system and surface coolers for about one month

bad condition on visual inspection in a plant where two machines of the same rating and age were operating. The insulation resistance of the winding which had to be replaced was found to have a ratio of more than 7 to 1 between the 2,500-volt and 20,000-volt tests, respectively. The insulation resistance of the other machine was found to have a relation of approximately 1.25 to 1 for the 500-volt and 10,000-volt tests and 1.2 to 1 for the 2,500-volt and 10,000-volt tests, respectively. The winding of this machine appeared to be in excellent condition.

While sufficient data have not been accumulated to permit final conclusions, they do indicate that a wide difference in insulation values determined by low and high voltage tests should lead one to suspect irregularities in the insulation. Efforts at conducting voltage tests under staged conditions by mechanical damage have met with poor success because of the difficulty of keeping reductions in the dielectric strength of armature bar insulation under control.

V—Insulation Power Factor

Power factor testing of generator windings is not in common use. Experiments have been made, however, to determine whether some test of this type may be useful and practical. The 60-cycle power factor of generator insulation has been studied for different winding temperatures and impressed voltages.

Equipment

Any well constructed and properly shielded power factor measuring equipment is satisfactory. Circuits of the test instruments must be thoroughly shielded and guarded to prevent interference from other energized equipment. Use of the ordinary wattmeter, voltmeter, and ammeter is not likely to give satisfactory results. Suitable commercial measuring equipment is available from several sources. A testing supply of ample capacity to furnish the charging current at the measurement voltage should be used.

Park and Skeats[4] have shown that generator winding capacitance can be determined fairly accurately by use of the formula $C = K_c \frac{\text{MVA}}{\sqrt{kv}(1+0.08\ \text{kv})}$ microfarads per phase.

The constant K_c has the following values:

	K_c	Assumed Peripheral Speed Ft/Min
Solid round rotors	0.0187	22,000
Salient-pole generators without amortisseurs	0.0347	10,000
Salient-pole generators with amortisseurs	0.0317	11,000

C is approximately inversely proportional to peripheral speed.

Capacitance of connecting cables must be added if included in the test.

Charging current at high voltage may be 25 per cent to 100 per cent above that determined by the capacitance constant alone, depending upon the extent of the corona losses, which vary with the impressed voltage.

Results

Power factor measurements on machine insulation may be affected by many conditions, most of which are similar to those outlined for d-c insulation resistance. The time of voltage application appears to have little effect on winding power factor unless it causes heating within the insulation. Winding temperature and moisture content will have a pronounced effect, and winding capacitance is, of course, an important factor. Voltage magnitude has an effect on power factor causing it to increase as the voltage is increased over the normal test range.

Insulation power factor should be nearly constant at each voltage below the ionization value.

Figure 8 shows the typical variations of winding power factor with different values of applied alternating voltage at different temperatures.

Power factor measurements have thus far produced little data which may be used to indicate insulation condition, other than moisture content.

No experiments have been conducted on dielectric loss characteristics by the subject committee. European engineers have had some success with this method, particularly as applied to control of manufacturing processes. It has received little attention as a means for supervising the insulation characteristics of an operating machine.

VI—Ionization Measurements

Both qualitative and quantitative ionization measurements[5] have been investigated to determine whether such measurements can be used to detect insulation irregularities in generator insulation. The quantitative tests were designed to obtain a characteristic showing the relative magnitudes of ionization discharge from a generator winding as the applied a-c voltage was varied, and to determine whether this might have any relation to the physical condition of the insulation or to its dielectric strength. Qualitative tests were designed to locate ionization points in the winding on the supposition that ionization would be present at weak points in the insulation.

Apparatus used for the qualitative tests is shown in figure 9. Equipment for the quantitative measurements was connected as indicated in figure 10. Complete shielding of the apparatus is necessary, and even then external disturbances due to radiations from energized equipment nearby are bothersome. For the quantitative tests the radiations in the radio frequency range were amplified, rectified, and measured by a sensitive d-c instrument. The measurements were relative only and not of any definite figure in amperes of ionization current.

Results of Qualitative Measurements

The qualitative ionization tests determined not only the impressed voltage at which ionization began, but were reasonably successful in determining the locations at which more severe ionization was present. On 6.6-kv and 11.4-kv generators having old winding designs varying in insulation structure from 100 per cent class *B* to all class *A* construction in the slot section, the voltage at which ionization was noted varied from about 1,000 volts to approximately 7,000 volts. The

Table II. Summary of Generator-Winding Insulation Tests* 1935–1940

Rating (Kva)	Voltage	Speed (RPM)	Armature Insulation Age (Yrs.)	Armature Insulation Type	Armature-Insulation Resistance Megohms	Time (Min.)	Voltage	Temp. (°C)	Armature-Insulation Power Factor Per Cent P.F.	Temp. (°C)	Voltage (Kv)	High-Voltage Breakdown (Kv) Armature 60 Cy.
12,000	11,400	750	16	B	2,000	6	500	20				35
12,000	11,400	750	15	B	1,150	10	500	20	11	20	6.6	45
20,000	6,600	1,500	22	B	300	10	500	22	6.7	22	3.8	39
20,000	6,600	1,500	22	B	350	10	500	22	6.5	22	3.8	43
14,000	7,800	720	30	A	310/185	10	500/5,000	20	11	20	4.5	46
					54/35	10	500/5,000	47				
68,750	13,800	1,800	0	B	200	10	8,000	36				
			2	B	208	10	8,000	36				
33,000	11,000	360	15	B	38/28	10	1,000/5,000	56				
55,000	11,000	360	5	B	285	20	5,000	48				
00,000	16,500	1,800	7	B	2,200	25	1,000	22				
15,000	13,200	94.7	2		36	10	1,000	22				26 (Before rewinding)
18,750	6,600	112.5	16	A	33	10	8,000	32	10	35	2.5	
									13	35	8	.8 (Min.) 21.4 (avg. of 18 coils)
30,000	12,000	1,800	10	B	32/26	10	5,000/15,000	28				
30,000	9,250	1,500	0	B	700/500	10	4,000/9,000	30	7.5/9.0	30	4/10	
3,500	12,000	1,200	27	A	16and17	1	1,000	6	22 to 29 (Arm & Fld.)	1	3.5	22.5 Min. (avg.—51.5 kv) (2 units—same rating)
28,600	13,800	1,800	11	B	74	10	470					8 to 14 (3 coils tested)
23,750	11,000	1,200	21	B	40,000/coil	3	500	11	6.7 (Avg.)	11	6	17 to 35 (1/3 of coils)
23,750	11,000	1,200	12	B	460	1	470	21	3.2	35	0.5	
3,500	2,300	1,800	9	B	1,000	1	470	21				
4,000	2,300	1,800	25	B	200	1	470	21				
8,000	11,000	1,800	23	B	340	1	470	21	8.9	31	0.5	
20,000	11,000	1,800	14	B	195	1	470	21	6.7	23	0.5	
23,750	11,000	1,200	14	B	955	1	470	21	3.5	50	0.5	
23,750	11,000	1,200	14	B	345	1	470	21	9.8	46	0.5	
43,750	11,000	1,800	10	B	140	1	470	21	5.4	24	0.5	
10,000	11,000	94	26	B	475/275	10	1,000	36/60				
10,000	11,000	94	25	B	670	10	1,000	63				
13,750	11,000	94	15	B	265	10	1,000	69				
10,000	11,000	94	15	B	235	10	1,000	60				
10,000	11,000	94	27	B	845/157	10	1,000	28/70				
12,000	11,000	116	26	B	311	10	1,000	69				
12,000	11,000	116	25	B	136	10	1,000	73				
12,000	11,000	94	24	B	540	10	1,000	39				
15,000	13,200	94.7	2	B	36	10	1,000	22				26 (Before rewinding two years earlier)
15,000	13,200	94.7	14	B	35	1	1,000	80				
12,500	13,200	1,800	11	B	1,270/300	10	1,000	41/79				
12,500	13,200	1,800	13	B	820/164	10	1,000	44/73				
30,000	12,000	1,200	6	B	10/7		4,000/12,000	(Round)	10	(Round)	10	14 (Old winding replaced in 1939)
			0	B	37/31		4,000/12,000	(Round)	8	(Round)	10	(New winding)
1,500	2,700	1,200	36	A	65	10	1,000	20	20	20	3	3.5
2,500	2,300	3,600	13	B	150/phase	2	1,000	20	18	20	3	6.5
27,777	13,200	1,800		B	1,500/phase	10	2,500	40	4.3	53	10	25 (38°C)
27,777	13,200	1,800		B					6.2	53	10	18 (53°C)
30,000	13,600	720	11	B	2,200/1,900	10	2,500/10,000	25				
30,000	13,600	720	11	B	6,500/2,500 (Ph-1)	10	2,500/10,000	30				26.3 (Avg.)
					5,800/2,700/800 (Ph-2)	10	2,500/10,000/20,000	30				
30,000	13,600	720	0	B	400 (1-Ph)	10	2,500	20				
					920 (All Ph)	10	2,500	20				
58,824	13,800	3,600		B	950	10	1,000	28				
30,000	13,270	300		B	1,000	10	2,500					
14,000	6,000	720	27	A	135/105	10	1,000/8,000	28	22/15	28	6	
1,500	11,000	375	0	B	1,200	5	25,000	30				
80,000	14,400	1,800	0	B	100	1	1,000	70				
					350/200	Final	1,000/10,000	33				
80,000	14,400	1,800	3	B	80	10	1,000	43				
80,000	14,400	1,800	2	B	19	10	1,000	45				
18,750	13,200	1,800	24	B	99/12	10	500	32/63				
18,750	13,200	1,800	24	B	125/25	10	500	28/74				
25,000	13,200	1,800	18	B	520/50	10	500	37/75				
31,250	13,800	1,800	3	B	900/190	10	500	34/72				
30,000	6,600	1,500	22	B	170/110	10	1,000/20,000	37	10	52	5	32.7 (Avg.)
24,000	13,800	1,800	21	B	100	10	1,000	47				
23,500	13,800	720	3	B	950	10	1,000	34				
58,800	13,800	3,600	0	B	1,500/2,100	10/35	1,000	27				
188,500	13,800	1,800/1,200	13	B	15/19	10	1,000	33				
188,400	13,800	1,800	13	B	40/21	10	1,000	25/43				
160,000	11,400	1,500	12	B	560 & 660	10	1,000	27	(Machine has two independent windings)			
24,000	13,200	1,800	21	B	330	10	1,000	21				
23,500	13,800	720	3	B	120	10	1,000	35				
35,000	11,400	1,500	17	B	1,000	10	1,000	42				
35,300	13,800	1,800	0	B	460	10	500	50				

* Insulation resistance data on 40 machines not listed because of lack of full rating information.

machine on which ionization was detected at 7,000 volts and 21 degrees centigrade, was a 7.8-kv class *A* insulated unit. When this winding temperature was raised to 47 degrees centigrade, ionization could be detected at about 5,000 volts.

Ionization was detected at 1,000 volts on a 6.6-kv machine with mica insulation at a point where the coil passed through an air duct at the center of the stator winding. Though signs of corona pitting were expected in the insulation and heavy paper protective covering actually no evidence of such damage was found.

Where an aerial was used for detection, the only radiations due to ionization which were picked up in the slot sections of the stators were at air ducts and at the outer edges of the stator iron, even though the voltage was raised to more than two times machine rated voltage. This may be explained partially by the shielding effect that the stator conductors receive in the slot sections. Ionization was detected at the end turns of all machines tested by this method, at voltages varying from 25 per cent to 50 per cent of machine rated voltage.

An attempt was made with the search aerial to locate points where intentional damage had been inflicted to the insulation of various generators, by bruising the insulation with hammer blows, by cracking the insulation in bending, and by cutting into the insulation structure with a knife. The qualitative measurements gave no clear indication that ionization had increased or that it developed at a lower voltage.

Results of Quantitative Measurements

Quantitative ionization tests were made to determine the relation of ionization discharge with change in impressed voltage and to determine whether the rate of change could be used to detect insulation damage or deterioration. Figure 11 shows the curves obtained on a class *A* insulated machine for all three phases, two phases separately, and for a section of another phase winding whose insulation had been intentionally damaged as previously described. It was thought that the curve would show a step type characteristic giving sudden increases of ionization units at increasingly rapid steps as the impressed voltage was increased. This characteristic does seem to be partially realized in the curves for the two separate phase tests, though not to the degree anticipated. The results on the winding section which had been damaged were somewhat surprising since the winding failed to ground as the voltage was approaching 16 kv. This is only 1,000 volts above the highest voltage at which a measurement of ionization units was made. The curve shape gives no indication of approaching failure.

VII—High-Voltage Tests—A-C and D-C

A survey of coil insulation strengths was made on a number of machines where the machine was being removed permanently from service or where the winding was to be replaced. The work consisted of a-c high potential tests, to breakdown, on different phases and different coil sections and, in some cases, was supplemented by tests using d-c voltage from Kenotron testing equipment. These tests were made in conjunction with other measurements on winding sections as found and on coil sections which had been subjected to various types of mechanical damage intentionally inflicted. Special attention was also given to determination of the relative a-c and d-c strength of winding insulation.

Effect of Age on Dielectric Strength

Generator armature winding insulation strengths were found remarkably high even after 20 to 30 years of service, as will be noted by reference to table II. There were occasional failures at voltages less than twice normal rated voltage attributable to mechanical injury which had developed in the insulation and which could not be seen until the winding was disassembled. Most of the breakdown voltages were far in excess of the voltage specified for new machines in the AIEE Standards. A 6.6-kv generator with 1915 class *B* insulation failed at the end-turns at approximately $6^1/_2$ times rated terminal voltage on several tests. This is the machine on which ionization was detected in the slot section at the air duct with an impressed potential of only 1,000 volts. It was impossible to obtain a failure on one of the armature bars after the end-turn brackets had been disassembled, though the voltage was raised momentarily to 72 kv and held at 68 kv (over 10 times normal) for a period of 5 minutes. This case is exceptional and is not intended to convey the thought that armature bar insulation has this safety factor as a general thing.

Rotor Dielectric Tests

Ten turbogenerator fields were tested to destruction, with breakdown voltages varying from 1 to 5.5 kv. Six of the fields punctured at values between 1 and 2 kv which indicates that, in order to prevent undue stress, routine field testing should preferably be done with a 500-volt source rather than with a 1,000-volt source.

Dielectric Strength—A-C Versus D-C

Numerous tests have been made to determine the relative strengths of generator insulation as determined by breakdown voltage using a-c and d-c test equipment. An established ratio between the two types of tests will permit use of low capacity d-c testing equipment on large armature windings.

Such tests were made by selecting a group of four to six coils, each at different locations, around the periphery of the stator for each type of test. Unusually low breakdown strengths were disregarded as being caused by abnormal weaknesses in the coil. Experiments made to date have given the following results:

Table III

Machine	Average Insulation Breakdown Strength: A-C Voltage (RMS) Kv	D-C Voltage Kv	Ratio D-C/A-C (RMS)
2.3-kv motor	13.2	20.8	1.6
2.3-kv motor	11.7	21.0	1.8
13.8-kv, 30-mva synchronous condenser	28.3	38.5	1.46
6.6-kv, 30-mva turbogenerator	34.0	46.7	1.38

Similar tests have been performed in the laboratory on a group of spare generator coils, no end-turn supports were used. The slot sections of the coil were grounded carefully by clamping them into metal troughs. The average 60-cycle breakdown was 65 kv. The d-c value varied from 150 to 175 kv. The ratio is approximately 2.5, which approximates values to be expected in cable insulations. It is thought the test set-up, by reducing ionization, may have more nearly represented a cable structure than it did a generator coil structure.

Relation Between Insulation Resistance and Dielectric Strength

Since the ultimate objective of this investigation has been to determine a test method or a group of tests which could be used to determine the true quality of generator insulation with regard to its ability to withstand high voltage, much time has been spent in attempting to find a relation between dielectric strength as determined by a-c and d-c breakdown and various d-c insulation resistance measure-

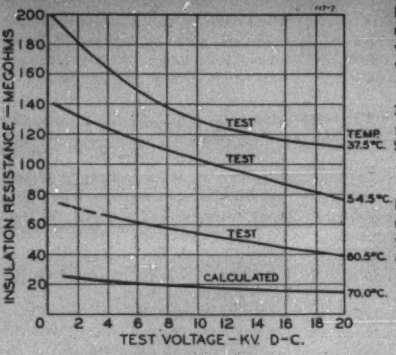


Figure 7. Insulation resistance versus test voltage at different winding temperatures

30,000-kw turbo-generator, 6.6 kv, 25 cycles, 1,500 rpm

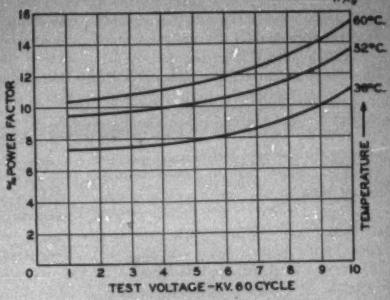


Figure 8 (right). Insulation power factor versus test voltage at different winding temperatures

30,000-kw turbo-generator, 6.6 kv, 25 cycles, 1,500 rpm

ments made at non-destructive voltages. In the early work, insulation resistance magnitudes were compared with 60-cycle breakdown strength on many coils. The investigation has been enlarged to include comparisons between insulation strength determined by a-c breakdown tests with dielectric absorption curve shapes and variations in insulation resistance characteristics at widely varying values of d-c voltage. Comparative insulation resistance and a-c breakdown tests have also been made under many conditions of deliberate mechanical damage to the insulation.

At present, no claim can be made that the ultimate objective has been attained. Comparisons between single insulation resistance measurements and dielectric strength seem to have little or no value and, under certain circumstances, the insulation resistance at moderate d-c voltages has been found to increase after the winding has been punctured on an a-c high potential test.

Location of Dielectric Failures

Stator winding insulation failures on breakdown tests occurred frequently at the end-turns. In some machines several coils were punctured, using both a-c and d-c, without a single failure occurring in the slot section. As indicated in table II the insulation strengths varied widely but invariably if a number of coils were tested, it was found that the weakest portion of the winding structure was at the end-turns.

Most end-turn failures occurred from the winding to the supporting brackets which always involved a flash through a short air gap. The insulation recovery after these failures was such that insulation resistance measurements did not detect any change in the winding characteristics. The failures which occurred in the slot sections appeared at the end of the slot or at the edge of an air duct in the stator iron. It is possible that ionization or swelling of the insulation at these points caused damages which reduced the dielectric strength but we have not been able to confirm the predominating cause. Very few machines have shown severe distress as a result of corona. In the few cases where effects of corona have been noted, the class *A* outer layer only has been affected. There has been no case where direct injury to mica insulation due to corona action has been discovered.

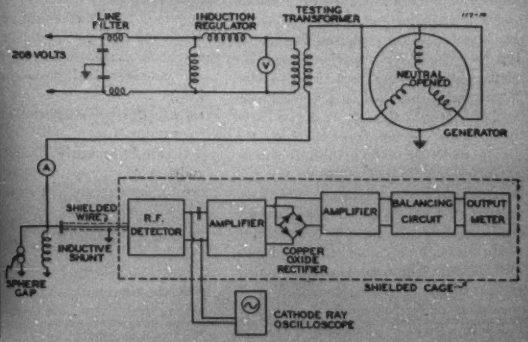
VIII—Conclusions

1. The industry will obtain increased value from its insulation testing if the known causes for variations in the results are carefully taken into account.

2. Insulation resistance varies widely with type and speed of machine, type and condition of winding, degree of cleanliness, temperature, moisture content, and extent of d-c charge on the winding. "Spot" readings, particularly, may be misleading unless carefully corrected for various factors affecting the reading. However, periodic

Figure 9 (left). Ionization detection apparatus ready for use

Figure 10. Connections of apparatus for measurement of ionization intensity in generator windings



readings may indicate a trend of the general condition of the insulation.

3. There is at present insufficient data to permit accurate correction of insulation resistance readings for all factors affecting these readings.

4. Slopes of the resistance-time curves may be of value as an indicator of insulation condition. They are satisfactory indices of excessive moisture content in the insulation.

5. Insulation resistance-time curves are extremely useful to indicate the progress of winding dry-out.

6. Comparisons of insulation resistance-time curves taken at widely different d-c voltages may prove of value in determining insulation condition.

7. The voltage effect on winding insulation resistance appears to be greater as the winding temperature is reduced, or as the moisture content is increased.

8. Power factor tests have given little indication of value in locating faults or incipient faults in generator windings. However, power factor measurements may prove to be an indicator of the trend of the general condition of the insulation including moisture content in a given machine if records are kept of periodic readings.

9. Sixty-cycle ionization tests have given no indication of value in predicting generator insulation condition or locating weak spots in windings.

10. D-c/a-c (rms) relative dielectric strength of generator insulation appears to approach $\sqrt{2}$. Additional tests must be made to establish this more accurately.

11. Dielectric strengths of old armature windings have been found to be generally high.

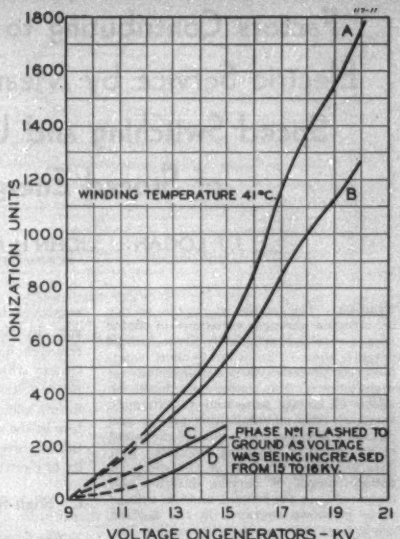
12. The end-turns of old generator windings appear to be weaker dielectrically than the slot sections.

13. Preferably, field windings should not be stressed to more than 500 volts d-c in routine testing.

Figure 11. Ionization intensity measurements on each phase of a generator winding

14,000-kw vertical turbo-generator, 7.8 kv, 60 cycles, 720 rpm

A—Phase 3
B—Phase 2
C—Phases 2 and 3 and section of phase 1
D—Section of phase 1



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(Editors Note: EEI headquarters at 420 Lexington Avenue, New York, N. Y., advises that the foregoing item is out of print, but that a supplementary mimeographed pamphlet, "Guides for Initial, Periodic, and Experimental Testing of Generator Insulation" is available in a limited quantity.)

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Factors Contributing to Improving Electric Service by Means of High-Speed Switching and Utilization of Stored Energy

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Synopsis: The quality of electric service as reflected through variations in motor speeds resulting principally from voltage surges is about as important to many manufacturing processes as is the continuity of such service. This paper sets forth the effects of voltage surges on an extremely speed-sensitive manufacturing process and describes how the effect can be minimized to the extent of becoming harmless. Test data are given which show the effects of voltage surges, of varying duration and magnitude, on the process, and the voltage surge is shown engraved in the finished product as the purchaser sees it. The maximum tolerable driving motor speed variation, without impairment to the product, is established and means are described for preventing a greater variation irrespective of the voltage surge intensity. An alarm system is described which is capable of instantly responding when variations in speed exceed tolerable limits. Use of a synchronous condenser, to supply energy during the interim of severe voltage disturbances or brief power failures, is effective in preventing motor-speed variations from exceeding the tolerable limits. These and other recent improvements will provide highly reliable electric service for the requirements of those manufacturing processes which are very exacting as to speed variations.

ACCORDING to reliable statistics, approximately 85 per cent of automatic interruptions to overhead power circuits result from transient disturbances which are removed within a fraction of a second after the circuit is de-energized, leaving the circuit undamaged. Experience backed by tests conducted in various classes of industrial plants has established the fact that power failures of from one-half to one second duration do not constitute a failure of service, provided the energy stored in current consuming apparatus is utilized during the interim such apparatus is disconnected from the normal power supply. It follows, therefore, that when a power circuit is interrupted from transient causes, if reconnected to the normal power source quickly enough, an interruption to service is averted. Under this practice the circuit breaker employed for controlling the power circuit, in effect, becomes a device which removes disturbances from the power system without impairing service. This paper describes the use of circuit breakers in this manner, together with related factors in the order of their contribution to the improvement in reliability and quality of electric service.

I. High-Speed Circuit Reclosure

A series of tests was made on the Georgia Power Company's system in June 1931 for establishing the feasibility of high-speed circuit reclosure. An automatic circuit breaker reclosing relay, providing for reclosing the breaker without delay after its initial tripping, was applied to a circuit breaker through which some 6,000 kw of industrial load was supplied over a 38-kv overhead circuit. The breaker controlling this circuit was capable of making the complete operation, from closed position to open and closed position again, in about 40 cycles. (All references to frequency are on a 60-cycle basis.)

Time-delay undervoltage-type push-button stations were installed for controlling several motor contactors in one of the textile plants served from this circuit, replacing conventional instantaneous-type push-button stations. The 38-kv circuit was then short circuited several times by drawing pieces of fuse wire across phases. In every test the arc was extinguished by the circuit breaker opening and did not restrike when the circuit was reconnected to the power source, after having been disconnected for about 40 cycles. All motors in the plant equipped with instantaneous-type push-button stations were shut down from the voltage disturbances, but those controlled by the time-delay undervoltage devices continued in operation. The maximum speed drop of these particular motors which were driving twisting frames varied between 10 and 15 per cent during the interim. According to textile experts these speed variations did not appreciably lower the quality of the yarn, and the strain on the motors appeared to be less severe than restarting them from a standstill.

The tests attracted considerable interest and new reclosing relays, or modified conventional reclosing relays, were developed for this new reclosing practice, which was quickly adopted by several power companies in the Southeast.

High-speed circuit reclosing with a duty cycle of 0–15–120 seconds was applied on most of the circuit breakers controlling overhead circuits on Georgia Power Company's system. Certain motor operated breakers necessitated delaying the second reclosure for 45 seconds or more, in order to provide time for the operating mechanism to relatch after tripouts immediately following the first reclosure. After about 15,000 automatic operations of circuit breakers equipped for high-speed circuit reclosure, not one breaker failure has been traced to this reclosing practice.

An early obstacle to the application of high-speed circuit reclosing was the time required for certain types of protective relays to part contact after closing to trip the breaker. The geared-type relays, in particular, then required about three-fourths of a second to part contact and obviously would retrip the breaker upon the initial reclosure. New contact arrangements providing for contact separation in one-fourth second or less were employed.

More than 12,000 interruptions to circuits supplying loads varying from a few hundred kilowatts up to 25,000 kw have been prevented on the Georgia system through the medium of high-speed circuit reclosure during its ten years' use, the effects of circuit tripouts being no more harmful than ordinary voltage surges. Below is a table showing the ten years' performance of certain circuits equipped for high-speed reclosure:

Number of Circuit Tripouts	10,000	100%
Successful Reclosures:		
1st instantaneous	8,400	83.25%
2nd 15–45 seconds	1,084	10.05%
3rd 120 seconds	143	1.42%
Circuit Lockouts	533	5.28%

Actually, the proportion of successful first reclosures including all operations is

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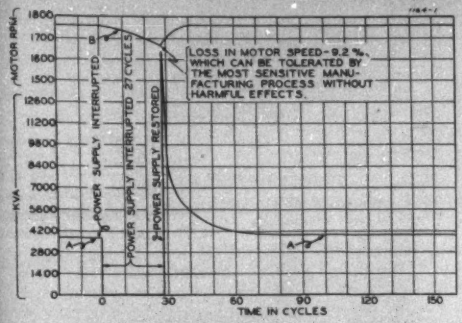

MOTOR RPM
KVA
LOSS IN MOTOR SPEED-9.2 %, WHICH CAN BE TOLERATED BY THE MOST SENSITIVE MANUFACTURING PROCESS WITHOUT HARMFUL EFFECTS.
POWER SUPPLY INTERRUPTED
POWER SUPPLY INTERRUPTED 27 CYCLES
POWER SUPPLY RESTORED
TIME IN CYCLES

Figure 1. Results from oscillographic analysis of effectiveness of high-speed circuit reclosure in preventing interruptions

Note that load, curve *A*, after circuit tripout and reclosure is practically normal within one-half second after being reconnected to the power supply, and that the speed variation, curve *B*, of a 7.5-horsepower motor is negligible

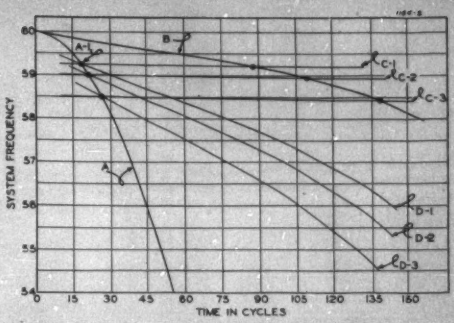


Figure 2. Inertia-relay operating characteristics

Curves *A* and *B* represent, respectively, speed changes for complete and partial loss of power source. Curves *C*-1, *C*-2, *C*-3, and *D*-1, *D*-2, *D*-3 represent, respectively, three of several possible relay-response slopes without and with the inertia element damped. The relay closes contact where slope, say *C*-1, crosses curve *A* or *B*

above 85 per cent instead of the 83.25 per cent shown, because the tabulation includes 2.3-kv and 4-kv circuits, the performances of which are hampered by tree grounds; and omits some 5,000 operations of 38-kv and 44-kv circuits supplied from automatic or semiautomatic stations where the records might be questioned for lack of devices capable of accurately recording the sequence of breaker operations.

Power consumers, particularly the industrial class, receive the greatest benefits from high-speed circuit-reclosing practices. According to records and observations a power failure, if for only a few seconds, stops completely or seriously curtails the average industrial plant output for five to ten minutes and in many cases as much as one-half hour.[1]

The portion of the load that actually "coasts through" the time required for clearing faults from and reconnecting the circuit to the power source varies, but when motor controls are adapted for this practice, as described under section II following, the service interrupted is negligible, the effects being no more harmful than disturbances that cause moderate light flicker. Figure 1 shows oscillographic results of a test for determining the amount of load actually interrupted during the interim the circuit is disconnected from the power source. The load was disconnected from the normal power source for 27 cycles during which time stored energy supplied the requirements. The fact that the magnitude of the load was practically normal within one-half second after being reconnected to the normal power source is proof enough that for all practical purposes there was no service interruption.

II. Application of Time-Delay Undervoltage Devices

Control apparatus usually supplied with motors incorporates undervoltage protection for the larger or more important motors. Unless specified by the purchaser, this protection is generally of the instantaneous response type and will shut down the motors for voltage dips on the power supply.[2,3] This necessitates restarting the motors after each voltage dip, with resulting loss in production and, in many cases where continuity is essential, of upsetting the entire process for extended periods of time with consequent heavy loss in raw material. Application of suitable time-delay undervoltage protective apparatus will reduce such losses to the practical minimum.

This improved type of undervoltage protection is becoming standard practice, the older instantaneous types having proved entirely unsatisfactory for use on important motors supplied from large interconnected power systems, because of the large number of voltage surges resulting from atmospheric disturbances usually in the form of lightning or sleet. The great majority of these voltage disturbances are cleared from power systems within one second or less, or the fault is so far removed that the surge voltage at the particular location does not drop below 65 per cent of normal. Consequently, the disturbances should be of little concern when the motors are properly protected by time-delay undervoltage devices

Voltage surge tests conducted in many textile plants employing speed-sensitive manufacturing processes indicate that the drop in motor speed in event of a

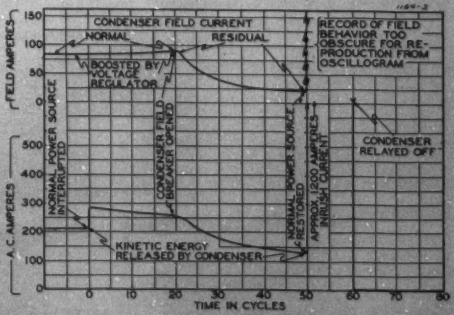
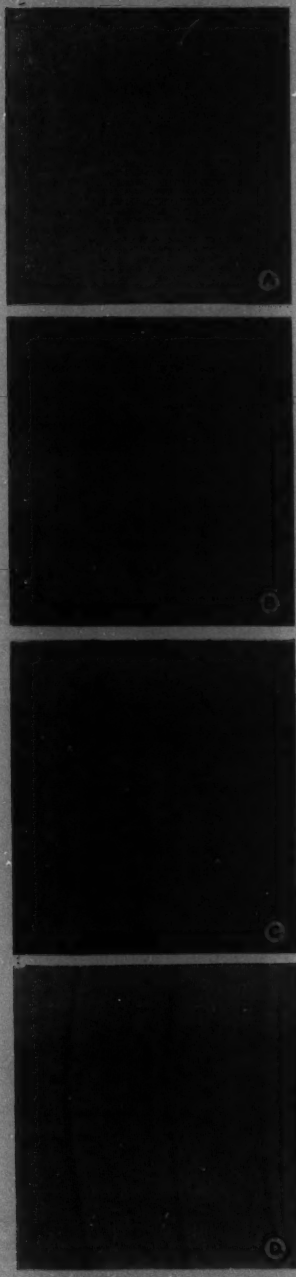


Figure 3. Graphic representation showing effects of high-speed circuit reclosure on synchronous condensers left connected to the circuit with the excitation source removed

Slow decay in field current makes this an unsafe practice. Condenser should be disconnected some 10 to 15 cycles in advance of restoring normal power source



complete power failure for one second is generally less than 20 per cent and that shutting down motors for such speed variations would do more harm than good, even ignoring the trouble of restarting. In fact, the practice of allowing essential motors to be shut down for voltage disturbances of any duration, so long as the motor continues to rotate, is questionable. There are links in many manufacturing processes that are adversely affected by rapid and prolonged speed changes, but usually stopping the process only aggravates matters. Such processes or links in processes should be given special consideration with the view of preventing objectionable voltage surges from being reflected on to the power source driving the particular motors. Means for accomplishing this are discussed under section V.

Continuity of operating through voltage disturbances is not essential, from the standpoint of production or quality of the product, for certain motors in most industrial plants. Whether these motors should be protected by time-delay undervoltage devices is a matter of individual consideration.

Synchronous motors, of course, require special consideration and generally should be disconnected from the line as quickly as possible following an out-of-step condition, unless the motor has excellent pull-in torque characteristics. Even then it would probably be better to provide field removal and restoring features and, possibly, automatic unloading devices.

Figure 4. Swatches of hosiery tubing knit from yarn produced under conditions of repeated voltage surges imposed on the power supply

	Surge Voltage (Per Cent)	Surge Duration (Cycles)	Motor-Speed Variation (Per Cent)	Yarn Quality
A	60.0	61	2.2	Good
B	0.0	31	10.2	Good
C	14.7	61	13.7	Defective
D	13.5	122	27.9	Poor

III. Treatment of Synchronous Apparatus

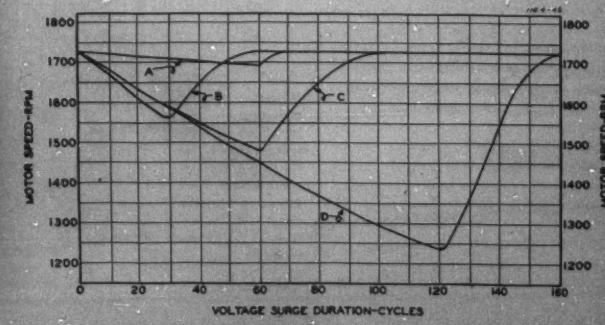
A 3,000-kva synchronous condenser connected to one of the circuits originally equipped for high-speed circuit reclosure required that the initial reclosing time be delayed to allow the fault more time to clear. The condenser in some instances prolonged the arc. An analysis of this problem revealed that suitable relays were not available for the purpose of removing the condenser from the line quickly enough, in order to avoid purposely delaying the initial reclosing time as much as one second or more, thereby defeating the purpose of high-speed circuit reclosure.

Reverse power and frequency responsive relays were tried but when adjusted to operate in about one-fourth of a second, the maximum allowable without purposely delaying the circuit initial reclosure, the condenser would often be unnecessarily disconnected.

In order to solve this problem, the authors developed a relay operating on a new principle, that is, the rate of speed or frequency change. This device, called an inertia relay, combines high speed response with reliability and is ideally suited for not only this application but for other uses discussed later.[4]

The relay differentiates between the relatively gradual rate of speed or frequency change on large power systems where millions of pound-feet[2] of inertia are involved and the rapid and erratic changes that occur on small portions of the system suddenly cut loose from the main power source and left without, or greatly deficient in, power supply.

Referring to figure 2, which shows the inertia-relay operating characteristics,



the relay can be adjusted to operate at any desired point along curve *A*, say at point *A*-1, for disconnecting synchronous condensers or an overloaded generating plant from circuits equipped for high-speed reclosing, this being accomplished in time to allow reconnecting the circuit to the system without delaying the reclosure. The maximum speed change expected on a power system under conditions of ordinary frequency disturbances follows some line usually well above curve *B*, to which the inertia relay will not respond if adjusted to operate on the slope represented by characteristic curves *D*-1, *D*-2, *D*-3 or some other of this family of curves. The relay can be adjusted to operate on the slope represented by curves *C*-1, *C*-2, *C*-3, and so on, if desired by simply lessening the damping effect on the inertia element. Also, the relay can be adjusted to respond within ten cycles or less for curve *A*. However, this would usually be undesirable because of waste in the kinetic energy stored in the rotors of spinning capacity so disconnected.

One of these relays is employed on the Georgia system for sectionalizing a 45,000-kw load in a manner for leaving load within capacity on a local 16,000-kw generating plant when the primary power source, a 110-kv transmission line, is involved by transient disturbances.[4] The relay detects the loss of the 110-kv source and accomplishes sectionalization in time to permit high-speed circuit reclosure to the transmission line without intentional delay, thus avoiding interrupting any portion of the load for transient faults involving the 110-kv source.

Five synchronous condensers and five small automatic hydroelectric plants connected to circuits equipped for high-speed circuit reclosure are also supervised by these relays. Four other installations for similar purposes are now under way.

Incidentally, the relay in addition to sectionalizing the 45,000-kw load area referred to above has proved to be faster and more positive than protective relays in disconnecting the faulted 110-kv line from the hydroelectric plant in time to prevent "swamping" the plant. This could not be done satisfactorily with conventional power directional relays, consequently, two other applications of the inertia relay for similar purposes are being studied.

Whether to disconnect synchronous condensers operating on circuits equipped for high-speed reclosure or to remove their sources of excitation only, during the interim the circuit is disconnected from the power source is a question frequently referred to the authors. Figure 3 shows the results of removing the excitation source only, and indicates that the magnetic energy stored in the machine is not dissipated in the field discharge resistor rapidly enough to make this a safe practice.

IV. Variation Tolerance in Motor Speeds

The foregoing sections of this paper deal primarily with improving the quality of electric service by reducing what otherwise would be momentary interruptions to electrical disturbances no more harmful than ordinary voltage surges.

Moderate voltage disturbances can be tolerated by the majority of users of electric service without harmful effects. However, some manufacturing processes are adversely affected from voltage surges to the extent that precautionary measures must be taken for minimizing the effects. In many instances the effects of voltage disturbances have been considered so damaging to the finished product that a local power supply is provided in preference to accepting the consequences of voltage surges that accompany electric service supplied from large transmission systems. A few of the processes which are unusually sensitive and adversely affected by voltage disturbances are employed in the manufacture of rayon and silk; high quality cloth; pulp and paper; broadcasting stations; printing presses.

The damaging effects of voltage disturbances are transmitted to the finished product generally through driving motor speed changes that result from the drop in voltage. Realizing the seriousness of this problem the authors have conducted extensive tests jointly with industries served by Georgia Power Company for the purpose of establishing what might be called a voltage "tolerance factor." The precision with which such a tolerance factor has been established for an unusually delicate or speed-sensitive process should be of interest, particularly to those who question the ability of a power system, subject to frequent lightning storms, to render satisfactory service to industries employing processes which require almost constant speed.

The test procedure provided for spinning yarn while the spinner-driving motor power supply was being subjected to repeated artificial voltage disturbances of varying intensity and duration. Oscillographic records of the voltage disturbances and motor speeds were obtained for each series of tests and the yarn marked in a manner for identifying that made under each of four surge test conditions. The quality of the yarn with respect to variations in size and dyeing characteristics, was determined with uncanny accuracy by textile engineers. So accurate were the methods employed, that the yarn size could definitely be tied in with the motor speed, even to the extent of distinguishing that produced during the period of decreasing motor speeds from that produced during the period of accelerating speeds which followed immediately the restoration of normal voltage.

Sections of the four batches of yarn produced under power surge conditions were next knit into hosiery tubing and dyed in a sensitive shade for bringing out dyeing defects. Figure 4 is a reproduction of a photograph of the swatches of hosiery tubing which were knit from yarn spun during the four surge tests. Associated with each swatch is a motor speed curve, corresponding alphabetically with the swatch designation, showing the motor-speed variation for each artificial voltage surge which was repeated every 20 seconds during the test. The effects of the voltage surges as reflected through the driving motor can be seen as bars, faintly in swatch *C* and clearly in

Motor-speed variations in the area above curve *A*, do not damage material produced under extremely speed-sensitive processes. Curve *B* represents the frequency produced by a 2,000-kva synchronous condenser when supplying 2,700 kw of load. Curve *C* represents speed of motors so driven. Load was disconnected from condenser at *B*-1 and reconnected to the normal power source; otherwise, motor speed would have followed trend of *B*-2

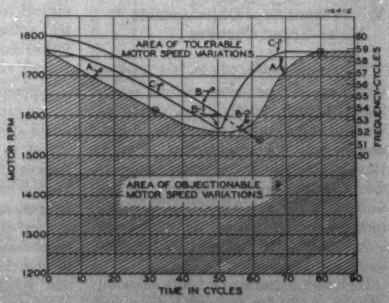


Figure 5. Tolerable and objectionable motor-speed variations

swatch *D*. The yarn produced under surge conditions represented by swatches *A* and *B* is classed as normal production by the textile engineers.

A summary of conclusions reached after analyzing the test results follows:

1. The principal interest of the textile company in regard to the effects of electrical disturbances may be measured by the degree to which the spinning machine driving motor speed is affected. Motor-speed variations of not more than 10 per c nt in one-half second can be accepted without great concern. Motor-speed variations of 15 per cent during a one-second period lead to variations in yarn size and dyeing disturbances which may be considered objectional. Speed variations on the order of 25 to 30 per cent during a two-second interval lead to pronounced loss of dye quality, due to marked variation in yarn size.

2. A signal system responding to motor-speed changes greater than that tolerable could be employed to advantage for advising the spinning production supervisor that yarn being spun was outside acceptable limits and should be segregated from regular production.

3. Voltage disturbances which do not reduce the driving motor torque below the pullout value are of little concern as the motor slip is increased less than ten per cent. Disturbances that reduce the torque below the pullout value, usually about 65 per cent normal voltage, must be limited to one-half second if the yarn spun is kept within acceptable limits.

4. The effects of voltage disturbances can be reduced to tolerable limits by means of high-speed clearing of faults, or the use of synchronous apparatus for maintaining voltage during system disturbances, to a value above the motor pullout point.

The signal system referred to in (2) above would require an initiating relay of unusual accuracy; otherwise yarn outside acceptable limits might get through unnoticed until too late, thereby causing a large shipment to be rejected as being outside acceptable limits. The inertia relay is ideally suited to initiate a signal for this purpose.

V. Prevention of Objectionable Motor-Speed Changes

Voltage-tolerance factors for various manufacturing processes can be established through suitable tests, similar to those described under section IV in connection with the manufacture of yarn. Having determined the voltage requirements for rendering satisfactory service to a particular speed-sensitive manufacturing process, means for restricting motor-speed variations to within tolerable limits can be considered.

High-speed clearing of faults offers an effective means for preventing damaging motor-speed changes. It was determined from tests described under section IV that zero voltage for one-half second was not objectionable in this particular extremely speed-sensitive process, in that the quality of the yarn was not appreciably lowered by subjecting the spinning motor power source to repeated power failures of one-half second duration. Refer to *B*, figure 4. For reasons more attractive than the prevention of damaging motor-speed variations, high-speed clearing of faults on transmission networks is very desirable and in many instances essential in order to promote system stability and reduce damages from power arcs. Unfortunately, however, this means for preventing motor-speed variations cannot be universally applied, principally because of fuse coordination problems which are encountered on most power circuits supplying industrial plants.

Objectionable motor-speed variations resulting from voltage disturbances reflected on to industrial plant power sources from the transmission system can be prevented where local generation is available and at a very reasonable cost. This may be accomplished by inserting a reactor between the plant bus and the transformer bank connecting the plant to the transmission system. The impedance of the reactor should be such that the local generating source can maintain voltage on the plant bus in excess of motor pullout values, usually about 65 per cent normal. Such an arrangement would limit motor-speed changes during the time of voltage disturbances on the transmission system to less than ten per cent or to within tolerable limits for even the most delicate or speed-sensitive manufacturing processes. Refer to *A*, figure 4. The reactor should preferably be normally short circuited by a high-speed circuit breaker controlled automatically by the transmission system voltage The circuit breaker should be opened only when the transmission system voltage, as measured on the transformer side of the reactor, is below motor pullout values.

Synchronous condensers offer a reliable means for preventing objectionable motor-speed variations. Kinetic energy stored in condenser rotors is generally sufficient for supplying a load equal to the kilovolt-ampere rating of the condenser for one second or more before the frequency drops to a value detrimental to speed-sensitive processes. This would involve high-speed switching, the load and synchronous condenser being disconnected from the main power source the instant the bus voltage dropped below motor pullout values. When voltage returned to normal on the main power source, the condenser would be disconnected from the load a few cycles in advance of transferring the load back to the main power source The condenser would then be returned to normal operation in the usual manner, preferably by automatic means

Figure 5 shows results when supplying 2,700 kw of load from a 2,000-kva synchronous condenser for 50 cycles, curve *B* representing the frequency supplied by the condenser. Motors driven from the synchronous condenser followed curve *C* which remained above curve *A*, the boundary of tolerable motor-speed variations for unusually speed-sensitive manufacturing processes. The condenser was disconnected from the load at *B*-1, a few cycles in advance of reconnecting the load to the main power source. Transfer of the load from the failing power source to the synchronous condenser and back again to the normal power source was accomplished smoothly by automatic control means. The voltage regulator controlling the condenser excitation prevented the bus voltage from dropping below 80 per cent normal which was well above the motor pullout value.

The use of synchronous apparatus connected to circuits equipped for high-speed reclosure for reducing voltage and frequency disturbances during the interim the circuit is disconnected from the normal power source is standard practice on the Georgia Power Company system. This practice is made possible through the inertia relay development which provides for positive isolation of the synchronous apparatus a few cycles in advance of reconnecting the circuit to its normal power source. The result gives the appearance of a short interval of reduced rather than apparent zero voltage. Best results are had by keeping the synchronous apparatus connected to the load until some 10 to 15 cycles prior to the restoration of the normal power source Reference to figure 3 shows that by this practice a great deal of kinetic energy can be fed into the load from synchronous machines thereby reducing the severity of voltage disturbances.

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High-Pressure Gas as a Dielectric

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Synopsis: Impulse and 60-cycle breakdown strength of sphere gaps, rod gaps, and of samples built up of solid and fluid dielectrics are reported. The tests were made in nitrogen up to 200 pounds per square inch gauge pressure and in Freon up to 70 pounds per square inch gauge pressure. Dielectric strength values were compared with the breakdown of transformer oil between the same electrodes. Gap conditions were found for which the 60 cycle breakdown was twice its impulse breakdown.

RECENT interest in the dielectric strength of gases under pressure has been stimulated by the steadily increasing voltages used in power transmission as well as in X-ray and atomic physics work and by the shortcomings of atmospheric air and of oil insulation. Although scores of articles have been published on high pressure gas dielectrics during the last forty years, they contain practically no information on the impulse dielectric strength of gases at high pressure. This is a serious omission from the point of view of those interested in generating and distributing apparatus since the kind and amount of insulation in these apparatus are influenced greatly by impulse strength. The theoretical background related to the breakdown of gaps in gases is much too incomplete to permit the extrapolation of available data much beyond the exact conditions under which the data were obtained. Therefore, numerous general as well as specific breakdown data must be accumulated in order to make the proper utilization of high pressure gases as dielectrics.

This paper will present impulse and 60-cycle breakdown data between gaps in nitrogen up to 200 pounds pressure and in dichlorodifluoromethane (dichlorodifluoromethane, commercially known as "Freon" will be referred to in this paper as CCl_2F_2) up to 70 pounds gauge pressure. In each case, a comparison will be made with the breakdown of transformer oil at atmospheric pressure between the same gaps.

Figure 1. High-pressure electric test tank

Recent Work

Several valuable contributions have been made to our fund of engineering knowledge of high pressure gas dielectrics during the last decade. Paschen's law, which was looked upon by many as a basic law of the dielectric strength of gaps at different spacing and pressure, has been shown to diverge far from the data at pressures above about six atmospheres. This law states that the spark-over voltage of a uniform field gap in a gas is directly proportional to the product of the gap spacing and the absolute pressure. The breakdown of a fixed gap is lower than the breakdown predicted by Paschen's law at pressures above 100 pounds per square inch. In fact the data[1,2] indicate that for air tested between spheres at a pressure of 600 pounds per square inch the actual spark-over is 55 percent of that predicted from atmospheric pressure data by Paschen's law.

Some gases have been found[3] which have as much as three times the 60 cycle dielectric strength of nitrogen when tested in a uniform field at atmospheric pressure. Notable among them are CCl_3F with a dielectric strength of three times that of nitrogen and CCl_2F_2 the gas commercially known as Freon and in common use in mechanical refrigerators, with a dielectric strength of 2.4 times that of nitrogen at atmospheric pressure.

Most of the earlier dielectric strength tests were made at low pressure or small spacings. Recently d-c breakdown tests[3] on spheres have been made at pressures up to 600 pounds per square inch and 450 kv breakdown. These data show also how slight roughnesses of the electrodes reduce the breakdown by as much as 50 per cent at 600 pounds pressure. Other investigators[4] made test in air and nitrogen up to 1,700 pounds per square inch. They indicate that the rate of increase of dielectric strength of air with increasing pressure continues to decrease at least up to 1,700 pounds per square inch pressure. This and other work[5] indicate that although the dielectric strength of air and nitrogen are practically the same at atmospheric pressure, the dielectric strength of nitrogen increases less rapidly than that of air with increased pressure, particularly above 100 pounds per square inch.

Apparatus

The experimental data presented in this paper were obtained by tests in the special pressure tank shown in figure 1. The pressure tank is four feet in diameter by seven feet high. Although it was tested hydrostatically up to 400 pounds per square inch pressure, it has not been used above 200 pounds gas pressure for safety reasons. It has three five-inch diameter sight windows made of discs of

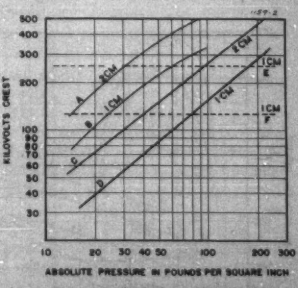

Figure 2. 60-cycle and impulse breakdown between 6.25 centimeter spheres

Curves *A* and *B* = CCl_2F_2, impulse and 60-cycle
Curves *C* and *D* = nitrogen, impulse and 60-cycle
Curve *E* = oil, impulse at atmospheric pressure
Curve *F* = oil, 60-cycle at atmospheric pressure

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1. For all numbered references, see list at end of paper.

methyl-methacrylate and an 18 inch steel door. A single high voltage bushing was used to carry the voltage into the pressure tank. This bushing was of the oil-filled type with a porcelain shell. The bushing was the same size both inside and outside the tank so that it could be used at maximum voltage with atmospheric pressure in the tank.

Two devices were used to adjust or change the electrodes inside the tank without opening the tank. One consisted of a screw which was operated by a shaft passing through the tank wall to a calibrated hand wheel. The gap electrode was mounted on the end of the screw and could be spaced accurately from the outside of the tank. The other consisted of a revolving platform installed in the bottom of the tank. The test samples which were made up of solid and gaseous dielectrics were good for only one breakdown determination. As many as twelve of these solid dielectric samples were placed on the revolving platform. These samples were connected, one at a time, to the voltage source by turning the turn table in the proper position with a driving mechanism which ran through a packing gland in the tank wall. These mechanisms saved a large amount of time by avoiding the necessity of opening the tank after each test.

Gases used were of a commercial grade obtained in high pressure tanks. The nitrogen was dried by passing it through a trap surrounded by liquid air. The CCl_2F_2 with high liquefying temperature was dried in columns of calcium chloride.

The CCl_2F_2 was drawn from the test tank through a compressor which recondensed the gas into its liquid phase and pumped it into a high pressure storage tank for future use.

The 60 cycle test voltage was supplied by a 350 kv, 1,000 kva testing transformer. The voltage was varied by controlling the field on the alternator connected to the testing transformer. The impulse voltage was supplied from a 500 kv impulse generator. The impulse voltage wave shape was checked and the breakdowns were observed with a cathode ray oscillograph connected across the test electrodes through a resistance divider. All impulse data presented herein were obtained with a $1^1/_2$–40 microsecond impulse wave.

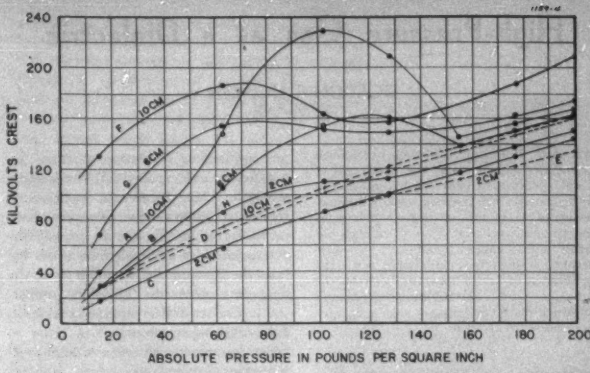

Figure 4. 60-cycle and impulse breakdown between one-half-inch square rod gaps in nitrogen

Curves *A*, *B*, and *C* = 60-cycle breakdown
Curves *D* and *E* = 60-cycle corona starting voltage
Curves *F*, *G*, and *H* = impulse breakdown

Test Results

Breakdown tests were made with the following three types of electrodes:

1. 6.25 centimeter diameter brass spheres.
2. Standard $^1/_2$ inch square brass rod gaps and
3. Electrode arrangements which included solid dielectrics.

The results of experiments made between the 6.25 centimeter spheres are summarized in figure 2. These data show the dielectric strength of nitrogen to increase as the 0.86 power of the pressure instead of increasing as the first power of the pressure in accordance with Paschen's law. The dielectric strength of CCl_2F_2 increases at a slightly smaller power of the absolute pressure than does the dielectric strength of nitrogen.

These gas breakdown curves represent both the crest value of the 60 cycle breakdown voltage and the crest value of the impulse voltage breakdown with a $1^1/_2$–40 microsecond voltage applied. The 60 cycle tests were made by increasing the voltage at a rate such that the voltage increased from approximately half of breakdown voltage to breakdown in one minute. An elapsed time of one minute was allowed between successive voltage applications. The average of ten breakdown determinations was used to establish a single datum point. The maximum spread of individual values was rarely over five per cent for the 60 cycle tests.

The impulse tests were made by applying five impulses of the same voltage at five or more steps two per cent apart in voltage, above and below the breakdown voltage. The voltage was lowered in two per cent steps until none of the five impulses broke down the gap. The voltage was also raised in two per cent steps until each of the five impulses at a particular voltage broke down the gap. The statistical voltage at which half of the impulses resulted in breakdown was taken as the breakdown value of the gaps. The maximum spread of individual values was with

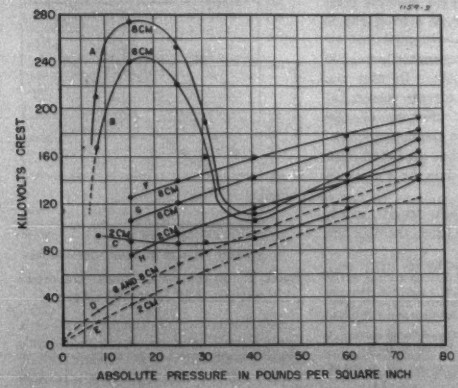

Figure 3. 60-cycle and impulse breakdown between one-half-inch square rod gaps in CCl_2F_2

Curves *A*, *B*, and *C* = 60-cycle breakdown
Curves *D* and *E* = 60-cycle corona starting voltage
Curves *F*, *G*, and *H* = impulse breakdown

few exceptions not greater than eight per cent of the breakdown value.

Observations showed that the breakdown of a gap was lower immediately after a breakdown. Therefore a procedure was followed such that a five minute interval elapsed between a flashover and the succeeding impulse application. Only one-minute interval was used after a voltage application that did not result in breakdown of the gap before another impulse was applied. This spread in the impulse data was probably increased by the fact that there was no effort to increase the free ion concentration within the tank by radioactive salts or an ultra-violet light source.

Breakdown of 6.25 centimeter spheres spaced one centimeter apart in 10-C transformer oil is plotted here for comparison. The oil breakdown tests were made at atmospheric pressure only. The transformer oil had a 60 cycle breakdown of 33 kv in a standard oil test cup with 0.1 inch gap spacing. The impulse strength of transformer oil with a $1^1/_2$–40 microsecond wave is slightly over two times its 60 cycle dielectric strength, while the impulse and 60 cycle breakdown strength of spheres in the high pressure gases are the same.

Rod-Gap Tests

Requirements of commercial high voltage apparatus other than the electrical insulation strength often dictate that the conductors adjacent to the insulation be made of some other shapes than spheres or curvatures of large radii. The standard $^1/_2$ inch square rod gap was therefore chosen for test electrodes to characterize the more severe conditions of non-uniform field encountered in high voltage apparatus.

60 cycle and impulse breakdown tests were made on this $^1/_2$ inch rod gap mounted in a vertical plane in the high pressure test tank, figure 1. Tests were made with both 60 cycle and $1^1/_2$–40 microsecond impulse voltages in nitrogen and CCl_2F_2 at various pressures and gap spacings. Figures 3 and 4 give the results of these tests. The corona starting voltage shown on figures 3 and 4 was taken by means of a cathode ray oscillograph which received its voltage from a high frequency amplifier placed across a shunt in series with the test gap

The 60 cycle breakdown of the rod gaps does not steadily increase with pressure. Figures 3 and 4 show how the breakdown voltage increases with pressure up to a critical pressure and then decreases with further increase in pressure until the breakdown of the gap is only slightly above the corona starting voltage of the gap. This critical pressure in the case of nitrogen is about 100 pounds per square inch gauge, while for CCl_2F_2 the critical pressure is only a few pounds above atmospheric pressure. The critical pressures are lower than those found by other investigators[1,4] on tests with point-plain electrodes. Goldman and Wul found the critical pressure for nitrogen to be about 150 pounds per square inch as compared with 100 pounds as shown in this report.

The impulse breakdown of rod gaps in nitrogen and CCl_2F_2 under pressure has only a remote resemblance to the 60 cycle breakdown curves. The impulse breakdown for rod gaps in nitrogen spaced at six and ten centimeters has a negative slope between 70 and 120 pounds per square inch, while the impulse breakdown of rod gaps in CCl_2F_2 increases steadily with increasing pressure. Figure 5 gives the impulse and 60 cycle breakdown of rod gaps spaced six centimeters apart in CCl_2F_2, nitrogen, and in transformer oil. The 60 cycle breakdown of CCl_2F_2 is about 2.2 times the impulse breakdown at

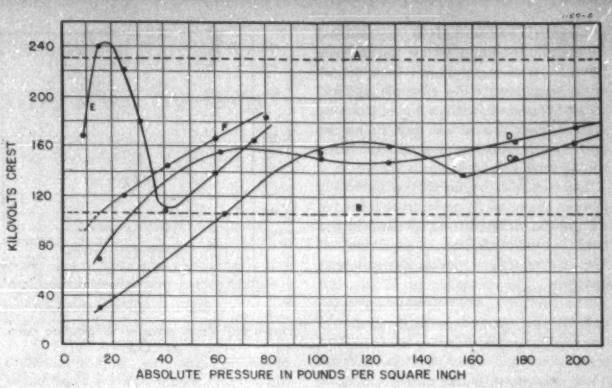

Figure 5. 60-cycle and impulse breakdown between one-half-inch square rod gaps spaced six centimeters in nitrogen, CCl_2F_2, and transformer oil

Curve *A* = impulse breakdown in oil
Curve *B* = 60-cycle breakdown in oil
Curve *C* = 60-cycle breakdown in nitrogen
Curve *D* = impulse breakdown in nitrogen
Curve *E* = 60-cycle breakdown in CCl_2F_2
Curve *F* = impulse breakdown in CCl_2F_2

Table I. Relative Dielectric Strength of Solid and Fluid Dielectric Arrangements in Transformer Oil and in Gases Under Pressure

INSULATION SET-UP	TYPE OF VOLTAGE	CREST BREAKDOWN IN PERCENT OF No. 1 SAMPLE 10-C OIL BREAKDOWN		
		10-C. OIL	NITROGEN 200 LBS./SQ. IN. GAUGE PRESSURE	C Cl_2F_2 70 LBS./SQ. IN. GAUGE PRESSURE
① ¼" PRESSBOARD 10" BY 10", ¼" DUCT, PRESSBOARD FILLER STRIPS, 5CM. TERMINALS	60 CYCLE PUNCTURE	100	88	132
② ¼" PRESSBOARD 10" BY 10", 5CM. TERMINAL, 3½", ¼" DUCT, METAL PLATE	60 CYCLE CREAPAGE	72	77	120
	1.5/40 μS. IMPULSE	142	115	143
③ ¼" PRESSBOARD 10" BY 10", ¼" DUCT, 5CM. TERMINALS	60 CYCLE PUNCTURE	56	37	
④ ¼" PRESSBOARD SPACERS, .5" BY .06" COPPER WIRE, .018" PAPER + .007" COTTON.	60 CYCLE	41	26	
	1.5/40 μS. IMPULSE	48	31	
⑤ 4", LEAD FOIL ELECTRODE, PORCELAIN TUBE 1" DIA. BY ¼" WALL	60 CYCLE	102	100	78

atmospheric pressure. It is very unusual to have a condition where the impulse breakdown of a gap is less than the 60 cycle breakdown. For example, the impulse breakdown with a $1^1/_2$–40 microsecond wave for a rod gap in air at atmospheric pressure is about 1.8 times the 60 cycle breakdown.

The fact that the impulse breakdown is greater than the 60 cycle breakdown for rod gaps in air has been explained on the basis of time lag before the gap is ionized in such a manner as to make it highly conducting. The condition in CCl_2F_2 gas where the 60 cycle breakdown greatly exceeds the impulse breakdown should be worthy of additional study. The reason for this unusual increase in the 60 cycle breakdown is not clear. There is evidence that the space charge in the gap is responsible for this unusually high breakdown.

Solid-Fluid Dielectric Combinations

Five different arrangements of solid and fluid dielectrics were tested for breakdown when immersed in 10-C oil, nitrogen, or CCl_2F_2. Schematic arrangements of the dielectrics and a comparison of voltage breakdowns are made in table I. Extreme care was taken in preparing the samples for these tests to see that the oil samples were completely impregnated and free from bubbles and that the gas-filled samples were thoroughly vacuum-dried and kept dry until they were tested. All of these dielectric arrangements have very non-homogeneous fields. The dielectric constants of the paper, pressboard, and porcelain used in these tests are all two or more times as large as the dielectric constant of transformer oil. Therefore, where the oil and solid insulation are in series, the oil must stand a disproportionately large part of the voltage stress. Since the dielectric constant of the compressed gases is substantially unity as compared with 2.2 for that of transformer oil, the voltage across the gas dielectric in series with solid insulation is considerably more than the voltage across the oil if it were made to replace the gas. This condition alone puts the gas dielectric to a considerable handicap when used in series with solid dielectrics.

It may be seen from table I that in general these combinations of solid and

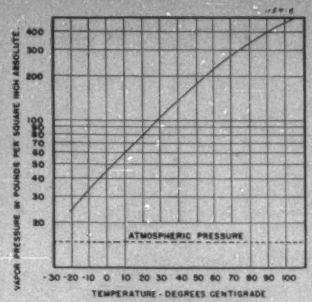

Figure 6. Vapor-pressure temperature curve of CCl_2F_2

fluid dielectrics had higher dielectric strengths in transformer oil than they did in nitrogen at 200 pounds per square inch pressure or CCl_2F_2 at 70 pounds per square inch pressure.

Temperature Effects

High voltage apparatus filled with compressed gases may be subjected to a wide range of temperature either by virtue of their ambient conditions or by the heat liberated within them.

This change in temperature will change the dielectric strength of the gaseous dielectric in different ways according to the manner in which the gas is supplied to the vessel. The following are generalizations based upon theoretical considerations and checked experimentally for CCl_2F_2 between spheres.

(*a*). If gas were supplied in a manner such that a constant gas pressure was maintained, the dielectric strength of the gas would change inversely as the absolute temperature.

(*b*). If the total quantity of gas in the system is unchanged, the dielectric strength of the gas should remain unchanged with change in temperature. This follows from the fact that the dielectric strength of a gas is proportional to its density.

(*c*). If the gas is in a closed system similar to condition (*b*) but the gas is saturated and an excess of liquefied gas is present in the system, the gas pressure will change with temperature according to the vapor pressure of the gas at the particular temperature. The dielectric strength of the gas will change in such a system nearly the same as the vapor pressure of the gas. Vapor pressure of CCl_2F_2 is shown in figure 6. It is obvious that such a system has much greater change in dielectric strength of the gas with change in temperature than do the systems (*a*) and (*b*).

Summary

1. The impulse and the 60 cycle crest breakdown strength of nitrogen are substantially the same when tested between spheres at less than radius spacing; the impulse and 60 cycle crest breakdown strength of CCl_2F_2 are likewise the same. Nitrogen at 175 pounds per square inch absolute pressure, CCl_2F_2 at 62 pounds pressure and 10-C transformer oil at atmospheric pressure break down at the same impulse voltage when tested between 6.25 centimeter spheres spaced at one centimeter. Under the same conditions the 60 cycle breakdown voltages of the three fluids are the same with nitrogen at 80 pounds absolute pressure, CCl_2F_2 at 25 pounds absolute pressure, and 10-C oil at atmospheric pressure.

2. The fact that there is a condition where the 60 cycle breakdown of a rod gap in CCl_2F_2 is over two times the impulse breakdown of the same gap under the same condition is disturbing to the orthodox theory surrounding the electrical behavior of spark gaps in gases.

The 60 cycle breakdown between rod gaps is substantially higher in nitrogen above 60 pounds per square inch absolute or in CCl_2F_2 above atmospheric pressure than in transformer oil. On the contrary, the impulse breakdown between rod gaps is considerably lower in nitrogen under 215 pounds per square inch absolute pressure and CCl_2F_2 below 85 pounds per square inch absolute pressure than in transformer oil.

3. The breakdown strength of solid insulations tested in nitrogen at 215 pounds per square inch absolute pressure and in CCl_2F_2 at 85 pounds per square inch absolute pressure as compared to its breakdown in transformer oil indicates that with but one exception the tests made in transformer oil showed higher strength than when made in the gases at the above pressures.

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An Automatically Reclosing Breaker for Co-ordinating Distribution Systems

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Synopsis: The increasing spread of distribution systems in which fault protection is afforded by fuses has resulted in long outages and high maintenance costs. Excellent coordination is possible with modern fuses, but their inability to differentiate between a permanent and a temporary fault results in frequent outages and costly service trips.

A new automatically reclosing circuit breaker with pronounced inverse time current tripping characteristics makes possible an improved radial distribution system in which outage and maintenance are reduced to a minimum. The effectiveness of coordination is increased to a point where an outage is confined to the immediate neighborhood of a permanent fault. Service trips are no longer necessary unless there is a permanent fault condition to be removed from the system.

Extended Distribution Systems Require New Type of Protective Equipment

IN recent years there has been a large increase in the number of distribution systems having long lines and small loads scattered over considerable territory. Such systems represent an increase in the use and application of electricity as well as affording users the benefits and conveniences of a reliable source of power. The continued extension and successful operation of these systems depends upon a low initial cost and a low maintenance cost.

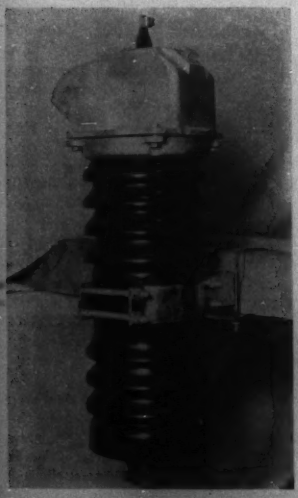

Figure 1. Single-pole automatically reclosing circuit breaker

The use of expensive lines and conventional apparatus for fault protection would result in low maintenance costs, but the installation cost could not be justified. Inexpensive lines with simple fuse protection for faults provide a low installation cost but result in high maintenance cost and unsatisfactory service. A high percentage of the maintenance cost of these extended systems is chargeable to the servicing required by faults. More than 80% of all faults are temporary and will not prevent the immediate restoration of service, so the elimination of service trips on such faults will materially reduce maintenance costs. The successful extension of such systems, therefore, depends upon the low installed cost of a device that will interrupt all faults and then restore service after all temporary faults.

The fault currents on these systems are relatively low and of such a value that distribution cutouts are used for sectionalizing, even to the use of five or more cutouts in series. The excellent coordination possible with modern fuses permits definite restriction of outages to the immediate neighborhood of a fault. On such systems, outages are of long duration and their restriction to limited areas greatly increases the quality of service. Therefore, a further requirement for a device to provide fault protection on such systems is its adaptability to an extensive coordination scheme. This will be accomplished if the device has a time current characteristic approximating that of modern fuses.

The necessarily inexpensive construction used on these systems, together with their length and exposure, has multiplied the number of faults to the point where simple fuses are inadequate for sectionalizing duty. Repeating fuses reduce the necessity for immediate service trips but require a periodic servicing and may not differentiate between a permanent and a temporary fault due to their short reclosing time. Close coordination is not dependable with repeating fuses, for a fuse is a thermal device and the heat stored in a protected fuse may result in its melting upon repeated operations of the fuse protecting it. It is seen, therefore, that an additional requirement is a time current characteristic which is not affected by repeated operations of the preceding protective device.

Since only a limited interrupting capacity is required, it is possible to make an inexpensive automatically reclosing oil circuit breaker to fulfill all of the requirements for operation on extended distribution systems. The requirements are:

1. Adequate interrupting ability.
2. Automatic reclosing to permit restoration of service after a temporary fault.
3. Pronounced inverse time current characteristic to permit close coordination on an extensive system.
4. Consistent time delay on tripping which is not affected by previous circuit conditions.
5. Reliable operation and low oil deterioration to reduce service trips to a minimum.
6. Low cost and a light weight to reduce the total installed cost to a minimum.

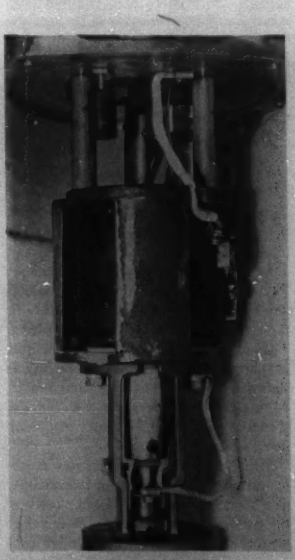

Figure 2. Interrupter and operating mechanism assembly withdrawn from porcelain tank

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1. For all numbered references, see list at end of paper.

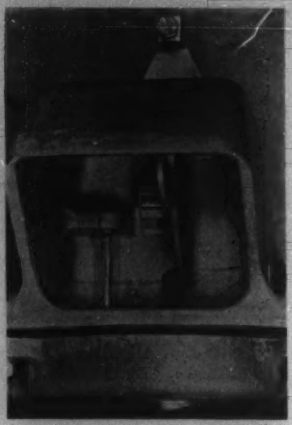


Figure 3. Indicating handle, oil gauge, and operation counter grouped under protecting hood

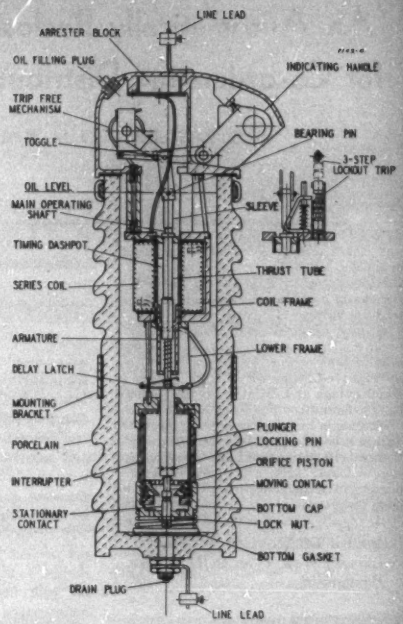


Figure 4. Sectional view of breaker with side view of lockout trip

7. Complete self protection in that no overload current (within the interrupting rating) or surge voltage shall damage the device.

From the application viewpoint the most important of these requirements is the inverse time current characteristic. The coordination possible with a breaker having the proper time characteristic greatly increases the scope of its application and makes possible the economical extension of low capacity distribution lines.

Construction and Operation of New Breaker

All of the above application requirements are fulfilled by the single pole automatically reclosing circuit breaker shown in figure 1. In addition, it has many other inherent features such as trip free closing; immediate manual reclosing after lockout; lockout on first interruption when manually reclosed against a fault; and multitap coil to permit ready change in rating. The interrupting chamber and all operating parts are easily removed in one unit as shown in figure 2. The indicating handle, oil gauge, and operation counter are grouped under an integral protecting hood, as shown in figure 3.

Figure 4 is a cross sectional view showing all principal elements of the breaker. The breaker is normally biased closed by the contact pressure springs, except during lockout. This differs from more conventional breakers in that, on tripping, the contacts are forced apart against spring pressure instead of being opened by accelerating springs. The energy required to operate the breaker is obtained from a series coil. The small size of coil used to operate the breaker and continuously carry overload currents just below the minimum tripping current is made possible by using an efficient type of interrupter that requires only a short travel. Wide separation of the contacts on lockout is obtained by releasing a spring that opens the breaker in the conventional manner and is reset, on closing, by means of the handle. Additional energy to interrupt heavier currents is obtained from the interrupter itself after the initial separation of the contacts.

Referring to figure 4, the armature when actuated by an overcurrent through the series coil moves upward and forces the entrapped oil from the timing dashpot. This action provides the inverse time characteristic on tripping. The shape of the time current curve is a function of dashpot size and port area together with the magnetic circuit and other factors. After a predetermined travel, the dashpot is opened, permitting the free armature to drive the moving contact open against the contact pressure springs. The moving contact opens rapidly for a short distance and then picks up the orifice piston which forces oil into the arc path resulting in interruption at the end of the first half cycle after the orifice piston starts to travel. On high currents the pressure developed within the interrupter will produce an additional driving force on the plunger thereby forcing oil into the arc path under a pressure proportional to the value of current being interrupted. The moving contact is free to move upward through the armature thus permitting overtravel on high current interruptions. The moving contact is prevented from reclosing at once by the delay latch which is not released until the armature again reaches its starting position. This results in a reclosing time of approximately five seconds. The time interval before reclosing permits the escape of gas from the top of the interrupter and entrance of fresh oil into the bottom. This flushing takes place through washer type valves that close instantly upon the appearance of pressure during interruption.

There is provided a simple, three step lockout trip which is notched up by the travel of the armature during each interruption. On the third interruption it breaks the toggle that holds the trip free mechanism in the closed position, thereby permitting the contacts to be driven to the extreme open position. The manual

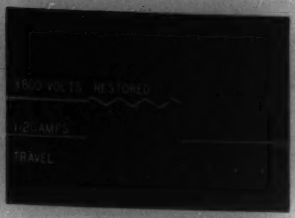


Figure 5. Interruption of 1,120 amperes at 13,800 volts

Note the increased overtravel at high currents

Figure 6. Interruption of 106 amperes at 7,200 volts

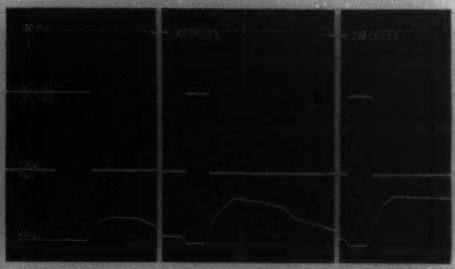
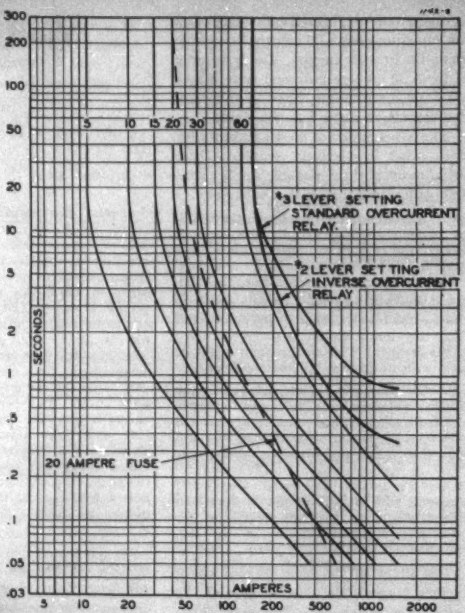


Figure 7. Three interruptions and lockout, 476 amperes at 7,200 volts

Note the travel of the contacts to the full open position after final interruption. (Portions of film showing breaker open between reclosures have been deleted from the original eight-foot film)

Figure 8 (right). Tripping-time current characteristics of new breaker

Note similarity to fuse link and relay curve



return of the indicating handle to the closed position will reset this toggle and the lockout trip and permit the breaker to close after the usual time delay. The lockout trip will be reset only to its second position from which it will lock out the breaker if there is a further interruption. If the fault has been removed from the line, the lockout trip will slowly reset to provide three step lockout on subsequent faults.

The series coil is made up of four separate windings. By connecting these windings in series, series-parallel, and parallel it is possible to obtain the six ratings from two coils, one coil furnishing the 5, 10, and 20 ampere ratings and the other coil furnishing the 15, 30, and 60 ampere ratings. To prevent damage to the coil from transient voltages, a suitable arrester is connected directly across its terminals.

Interruption and Lockout Tests

Repeated interrupting tests at both high and low currents on extremely fast circuits have demonstrated the high efficiency and low oil deterioration of the breaker. Indications are that the breaker can be in service many years before an oil change is required. The interrupting ability of the breaker is determined by the short-time current rating of the series coil rather than by any limitations in the interrupter. Figure 5 shows an oscillogram of a single interruption of 1,120 amperes at 13,800 volts. Figure 6 shows a single interruption of 106 amperes at 7,200 volts. Compare the travel record and note the additional travel of the contacts on the higher current interruption. Figure 7 shows three interruptions and lockout on 476 amperes at 7,200 volts. Note the tripping time, the reclosing time, and the travel of the contacts to the extreme open position after lockout.

Co-ordination Characteristics

The important attribute of this breaker is the time current characteristic. More time delay on tripping allows more time for coordination and therefore permits closer coordination between adjacent ratings. Consequently, as great a time delay as possible has been incorporated in this breaker particularly at the lower values of current just above the minimum tripping current. Since the different ratings are obtained by varying the number of turns on the series coil the curves will be parallel and identical in shape with only a shift in the current axis. Figure 8 shows the time current characteristics for the six ratings of 5, 10, 15, 20, 30, and 60 amperes. The time values have been obtained from oscillographic records of interrupting tests. Sufficient time delay has been provided so that all of these ratings can be coordinated in series. The possibility of coordination between these

breakers and fuses is further demonstrated by superimposing a 20 ampere fuse curve upon the breaker curves. The fuse curve is for a 20 ampere universal fuse link as used in distribution cutouts and is a representative curve for such links.

The coordination of these breakers with each other is relatively simple. There are, however, three possible applications in coordinating the breaker with fuses.

(1). A fuse can be selected such that it will be completely protected by the breaker, that is, the breaker will operate three times and lockout without melting the fuse. This would be a rather infrequent application.

(2). The fuse can be used to completely protect the breaker, that is, the fuse would clear the circuit without a single operation of the breaker. This arrangement might be used with transformer protective links.

(3). The fuse can be selected so that the breaker will clear the circuit once to permit the fault to clear, and then on the second operation, if the fault persists, the fuse will blow due to the stored heat remaining in it from the first operation. On the second reclosure the breaker will remain closed and the fault will be isolated by the fuse. In this arrangement the fuse would be the outermost protective device in the sectionalizing scheme.

The shape of the time current curve further suggests the coordination of the breaker with relays. The relay curve shown in figure 7 is for a standard overcurrent relay of the moving disk type. By adjusting it to the proper lever setting and proper current ratio, it is possible to have the relay curve very close to that of the breaker. With the setting shown, the breaker will consistently protect the relay and thus prevent tripping an entire substation. The time delay between operations of the reclosing breaker is sufficient to allow the relay disk to return to its starting point, so the coordination will be the same for each operation. With reclosing fuses, a much larger margin between the fuse curve and the relay curve would be necessary due to the short reclosing time. Here the relay disk would not return to its original position and there would be cumulative turning of the disk and consequent operation of the relay.

A further advantage of this breaker for fault protection on low capacity systems lies in the economies offered by the use of simple gaps for lightning protection. On this type of system a temporary outage is not serious and, with the coordination afforded by these breakers, such an outage due to lightning is confined to a small area and is removed upon the first reclosure.

Conclusions

An automatically reclosing circuit breaker meeting all of the requirements for use on extended distribution systems has been developed and proven by repeated tests. A particularly important aspect of this breaker is the pronounced time delay on tripping that permits coordination of several breakers in series and coordination of the breakers with standard fuses of comparable ratings. The coordination possible with this breaker greatly increases the scope of its application and permits the economical extension of low capacity distribution systems with improved quality of service.

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Short Circuits in Synchronous-Machine Armatures

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Synopsis: An approximate solution is obtained for the current in a short-circuited coil or group of coils in the armature of a synchronous machine operating under load. The solution is expressed as the sum of a series of harmonics whose terms are in geometric ratio. The results obtained are similar in form to those previously obtained for the short circuit of a complete phase winding, and they reduce to that for the single-phase short circuit in the limiting case when the coil group comprises a complete phase. An experimental check of the theory is given for the case of a short circuit of a single armature coil, and it is shown that close agreement is obtained between theory and test with respect to the fundamental component of current, though not with respect to the small higher harmonics of current.

SOLUTIONS for single-phase and three-phase short circuits of synchronous machines have been obtained by several authors, those of Park[1] and of Doherty and Nickle[4] being notable. These analyses, however, have considered only complete phase windings, and it is the purpose of this paper to extend the theory to treat short circuits of a single armature coil or group of coils. The solution obtained is applicable to machines operating under load, the effect of the load currents being obtained by an approximation that is sufficiently accurate for practical purposes.

As one coil or a group of coils is essentially a single phase, the analysis is similar in form to that of Doherty and Nickle for the single-phase short circuit. Following their procedure, a general expression is obtained for the magnetic flux linkages of armature and field windings. The constant-linkage theorem, which states that the magnetic flux linkages in any closed electric circuit are constant if the resistance is neglected, is applied to determine the initial currents when the short circuit occurs. From physical considerations, these currents are then separated into their sustained and transient components, and the proper decrement factors are applied to the latter.

Assumptions

For simplification, this analysis is applied to an ideal synchronous machine.[2] In such a machine, linear relationships exist between magnetic flux and currents in any part of the machine, so that the principle of superposition applies. The phase windings are identical and symmetrically placed about the armature, and there are only two field circuits, the main field winding in the direct axis and a short-circuited winding in the quadrature axis, both of which are symmetrical about their respective axes. Only fundamental harmonics of magnetomotive force and voltage appear in the phase windings.

In addition to the assumption regarding the ideal machine, other simplifications are made. The resistances of the group of short-circuited armature coils and of the field circuits are neglected in deter-

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1. For all numbered references, see list at end of paper.

mining initial currents in these windings but are taken into account in obtaining approximate values for the decrement factors. It is also assumed that the effect of the relatively large load resistance is to attenuate the unidirectional and even harmonics of induced current in the load circuit so quickly that these transient elements may be entirely neglected.

The solution is further simplified by making the assumption that, owing to the small mutual inductance between the phases and the coil group, the load currents are unaffected by the short circuit. The value of short-circuit current obtained under this assumption is regarded as the first approximation to the correct result. The effect of this current upon the load currents is then determined, and if the latter are changed an appreciable amount, the analysis is repeated, assuming that the load currents change by this amount. The second approximation is usually sufficiently accurate for all practical purposes, making further refinement unnecessary.

Analytical Development

Since the theorem of superposition is applicable to the ideal synchronous machine, the extension of Blondel's two-reaction method developed by Doherty and Nickle[3] is applied in appendix I to obtain expressions for the inductances of the field and armature circuits. Without loss of generality, the armature winding of which the short-circuited coils are a part is designated as phase A, and the angle between the axis of the coil group and that of phase A is β. Equations are then developed for the self and mutual inductances for the coil group, and it is found that these inductances may be conveniently expressed as functions of known design constants of the machine and the conventional inductances per phase.

Following the procedure that has been outlined, the inductance equations are used in appendix II to obtain the armature and field linkages of the machine. It is found that the results may be conveniently expressed in terms of the currents i_d and i_q defined by

$$i_d = i_a \cos\theta + i_b \cos(\theta - 120°) + i_c \cos(\theta - 240°) \quad (1)$$

$$i_q = i_a \sin\theta + i_b \sin(\theta - 120°) + i_c \sin(\theta - 240°) \quad (2)$$

The linkages in the short-circuited coil group are then

$$\psi_c = K_s\{(3/2)L_d i_d + M_d I_d\}\cos(\theta-\beta) + K_s\{(3/2)L_q i_q + M_q I_q\}\sin(\theta-\beta) + \{L_{SD}\cos^2(\theta-\beta) + L_{SQ}\sin^2(\theta-\beta)\}\times(i_s - i_a) \quad (3)$$

where i_s is the short-circuit current in the coil group. Expressions for the inductances and for the constant K_s are given in appendix I. The corresponding field linkages are

$$\psi_D = M_d i_d + K_s M_d (i_s - i_a)\cos(\theta-\beta) + L_d I_d \quad (4)$$

$$\psi_Q = M_q i_q + K_s M_q (i_s - i_a)\sin(\theta-\beta) + L_q I_q \quad (5)$$

These linkage equations will be used to obtain the solutions for the initial currents after the short circuit.

In conformity with the usual practice in the literature, the equations that follow are expressed in terms of reactances instead of inductances. The reactance corresponding to any inductance is the product of the latter and ω, where $\omega = 2\pi f$, f being the rated frequency of the machine. Thus $X_{SD'} = \omega L_{SD'}$.

Solution for Currents

When the short circuit occurs, spontaneous unidirectional components of current appear in the coil group and the field circuit tending to sustain the linkages at their initial value. The voltages that support these transient currents are generated through the collapse of the magnetic fields existing at the instant of short circuit.

As the machine rotates, the transient unidirectional current in the field induces a transient fundamental component of current in the coils, and this in turn causes a second harmonic in the field. This "reflection" from field to coils and back again gives rise to a series of even harmonics in the field and a series of odd harmonics in the coils, all of which are proportional to the average induced field current and all of which decay at the rate determined by the field decrement factor σ_f. Similarly the transient unidirectional current in the short-circuited coils causes a series of even harmonics in the coils and a series of odd harmonics in the field that decay to zero according to the decrement factor of the coil group, σ_s.

The rotating magnetic field due to the average field current supported by exciter voltage causes fundamental and higher harmonics of sustained current to appear in the short-circuited coils and also causes a series of even harmonics in the field.

Owing to the relatively large resistance of the load the transient unidirectional and even harmonics of current induced in the phases by the short circuit will be damped out very quickly and may be neglected. Because of the small mutual inductance between the coil group and the phases, only the fundamental of the induced odd harmonics that also appear is of appreciable magnitude. This component, being due to the fundamental of the short-circuit current in the faulty coils and the transient element of the average field current, will have a sustained and a transient value. The latter decays according to the field decrement factor. Neglecting the small harmonics, therefore, the induced load current can be represented by a sustained and a transient fundamental component. These must be added to the load current existing before the short circuit to get the total phase currents. The corresponding currents i_d and i_q, defined by equations 1 and 2, will then have the form

$$i_d = i_{d1} + (i_{d0} - i_{d1})e^{-\sigma_f t} \quad (6)$$

$$i_q = i_{q1} + (i_{q0} - i_{q1})e^{-\sigma_f t} \quad (7)$$

where i_{d0} and i_{q0} are the initial values before the short-circuit and i_{d1} and i_{q1} are the final sustained values. Approximate expressions for i_{d1} and i_{q1} are given in equations 19 and 20.

First Approximation to Short-Circuit Current. Following the procedure previously outlined, the first approximation to the short-circuit current is obtained by assuming that the load currents are unchanged. When the constant-linkage theorem is applied, it is shown in appendix III that if the short circuit occurs at $\theta = \theta_0$, the initial current in the coil group is

$$i_s = i_a + i' + i'' \quad (8)$$

The components i' and i'' are

$$i' = \frac{-2e_{SD}}{X_{SD'} + \sqrt{X_{SD'}X_{SQ'}}}\{\cos(\theta-\beta) + B\cos 3(\theta-\beta) + B^2\cos 5(\theta-\beta) + \dots\} + \frac{-2e_{SQ}}{X_{SQ'} + \sqrt{X_{SD'}X_{SQ'}}}\{\sin(\theta-\beta) + B\sin 3(\theta-\beta) + B^2\sin 5(\theta-\beta) + \dots\} \quad (9)$$

$$i'' = \frac{e_{SD}\cos(\theta_0-\beta) + e_{SQ}\sin(\theta_0-\beta)}{\sqrt{X_{SD'}X_{SQ'}}}\times\{1 + 2B\cos 2(\theta-\beta) + 2B^2\times\cos 4(\theta-\beta) + \dots\} \quad (10)$$

where

$$e_{SD} = K_s\{(3/2)X_{d^2}i_{d0} + X_{md}I_{d0}\} \quad (11)$$

and

$$e_{SQ} = K_s\{(3/2)X_{q^2}i_{q0}\} \quad (12)$$

are the direct and quadrature components of the voltage in the coil group prior to the short circuit, and

$$B = \frac{\sqrt{X_{SQ'}} - \sqrt{X_{SD'}}}{\sqrt{X_{SQ'}} + \sqrt{X_{SD'}}} \quad (13)$$

is a constant.

By the assumption made, i_a is unchanged, so that the additional current that is due to the short circuit is represented by the components i' and i''. The latter contains the d-c and even harmonics that arise to maintain the linkages at their initial value; therefore it is transient in character and decays to zero at the rate determined by σ_r. The other component, i', contains the odd harmonics and is proportional to the average field current.

As shown in appendix III, the average field current just after the short circuit occurs is

$$I_d(\text{average}) = G_0 I_{d0} \tag{14}$$

where G_0 is a constant defined by equation 60. Since the average sustained field current is I_{d0}, it is $1/G_0$ times as great as the initial value. The sustained value of i', therefore, is $1/G_0$ times as great as the initial value expressed in equation 9. The remaining portion $(1-1/G_0)i'$, is a transient and decays according to σ_f. The first approximation to the short-circuit current in the coil group is therefore

$$i_a = i_a + \frac{1}{G_0} i' + \left(1 - \frac{1}{G_0}\right) i' \varepsilon^{-\sigma_f t} + i'' \varepsilon^{-\sigma_r t} \tag{15}$$

The effect of the change in load currents being small, it will be found that this expression gives results that do not differ greatly from those obtained by the more accurate expression, equation 21.

The additional current introduced in the coil group by the short circuit is $(i_a - i_a)$, and for the reasons previously mentioned, its fundamental component is the only one that has appreciable effect upon the load currents. From equations 9 and 15, the sustained value of

$$(i_a - i_a)(\text{fundamental}) = I_1 \cos(\theta - \beta - \alpha_1) \tag{16}$$

where

$$I_1 = \frac{1}{G_0}\left[\left\{\frac{e_{SD}}{X_{SD}' + \sqrt{X_{SD}' X_{SQ}'}}\right\}^2 + \left\{\frac{e_{SQ}}{X_{SQ}' + \sqrt{X_{SD}' X_{SQ}'}}\right\}^2\right]^{1/2} \tag{17}$$

and

$$\alpha_1 = \tan^{-1}\left\{\left(\frac{e_{SQ}}{e_{SD}}\right)\frac{X_{SD}' + \sqrt{X_{SD}' X_{SQ}'}}{X_{SQ}' + \sqrt{X_{SD}' X_{SQ}'}}\right\} \tag{18}$$

Taking approximate account of the effect of this current, it is shown in appendix IV that the sustained values of i_d and i_q corresponding to equations 6 and 7 are

$$I_{d0} = -\frac{3}{2}\frac{x_q + X_L}{r^2 + (X_d + X_L)(X_q + X_L)}\left[X_{md} I_{d0} + K_S X_D \frac{I_1}{2}\cos\alpha_1 + \frac{r}{X_q + X_L} K_S X_Q \frac{I_1}{2}\sin\alpha_1\right] \tag{19}$$

$$i_{q1} = \frac{-r}{X_q + X_L} i_{d1} - \frac{3}{2(X_q + X_L)} K_S X_Q \frac{I_1}{2}\sin\alpha_1 \tag{20}$$

The corresponding expressions for i_{d0} and i_{q0} are obtained from those for i_{d1} and i_{q1} by putting $I_1 = 0$.

Second Approximation to Short-Circuit Current. The next step in the solution for the short-circuit currents is to assume that i_d and i_q have average values given by equations 6 and 7. Following the same procedure as before, the linkages of the coil group and the field circuits may be obtained and solved for the initial currents in the coil group and the field winding. Separated into its sustained and transient components and with the proper decrements applied, the second approximation to the short-circuit current in the coil group is

$$\begin{aligned} i = {} & \frac{2}{3}\{i_{d1}\cos\theta + i_{q1}\sin\theta\} - \\ & \frac{1}{G_1}\left[\frac{2\{e_{SD} - K_S(3/2)X_d'(i_{d0} - i_{d1})\}}{X_{SD}' + \sqrt{X_{SD}' X_{SQ}'}} \times \right. \\ & \{\cos(\theta - \beta) + B\cos 3(\theta - \beta) + \ldots\} + \\ & \frac{2\{e_{SQ} - K_S(3/2)X_q'(i_{q0} - i_{q1})\}}{X_{SQ}' + \sqrt{X_{SD}' X_{SQ}'}}\{\sin(\theta - \beta) + \\ & \left. B\sin 3(\theta - \beta) + B^2 \sin 5(\theta - \beta) + \ldots\}\right] + \\ & \varepsilon^{-\sigma_f t}(3/2)\{(i_{d0} - i_{d1})\cos\theta + (i_{q0} - i_{q1})\sin\theta\} - \\ & \frac{1}{G_1}\varepsilon^{-\sigma_f t}\left[\frac{\{(G_1 - 1)e_{SD} - K_S(3/2)X_d'(i_{d0} - i_{d1})\}\cos(\theta - \beta) + \{(G_1 - 1)e_{SQ} - K_S(3/2)X_q'(i_{q0} - i_{q1})\}\sin(\theta - \beta)}{(3/2)(X_{SD}' + X_{SQ}') + (1/2)(X_{SD}' - X_{SQ}')\cos 2(\theta - \beta)}\right] + \\ & \varepsilon^{-\sigma_f t}\frac{\{e_{SD}\cos(\theta_0 - \beta) + e_{SQ}\sin(\theta_0 - \beta)\}}{\sqrt{X_{SD}' X_{SQ}'}} \times \\ & \{1 + 2B\cos 2(\theta - \beta) + 2B^2\cos 4(\theta - \beta) + \ldots\} \end{aligned} \tag{21}$$

where

$$G_1 = \frac{X_{SD} + \sqrt{X_{SD}' X_{SQ}'}}{X_{SD}' + \sqrt{X_{SD}' X_{SQ}'}} \times \left[1 + \frac{2(X_d - X_d')(i_{d0} - i_{d1})}{3X_{md} I_{d0}} + \frac{X_{SD} - X_{SD}'}{X_{SD}' + \sqrt{X_{SD}' X_{SQ}'}} \cdot \frac{2X_d' i_{d1}}{3X_{md} I_{d0}}\right] \tag{22}$$

The solution for the coil current for the case of short circuit at no load is obtained by letting $i_{d0} = i_{q0} = i_{d1} = i_{q1} = 0$ in equation 21. This is equivalent to making $e_{SQ} = 0$ and $e_{SD} = K_S X_{md} I_{d0}$.

Because of the relatively small mutual inductance between the coil group and the phase and field circuits $(i_{d0} - i_{d1})$, $(i_{q0} - i_{q1})$, and $(G_1 - 1)$ are ordinarily small. Therefore it is usually possible to neglect the terms involving $\varepsilon^{-\sigma_f t}$ when making calculations using equation 21. For the sake of completeness, however, they have been included.

One component of the sustained short-circuit current is equal to the sustained load current $(3/2)\{i_{d1}\cos\theta + i_{q1}\sin\theta\}$. The other component is the sum of two odd harmonic series whose terms, in ascending order, are in geometric ratio. The ratio, B, is given in equation 13.

The expression for the short circuit current of the group of coils is similar in form to that given by Doherty and Nickle[4] for the single phase short circuit and their discussion of the effects of the machine constants upon the form of the solution applies equally well here. In the limiting case when the coil group comprises a complete phase, the solution for the condition of no load is exactly the same as theirs.

Decrement Factors

Expressions for the decrement factors may be obtained by the approximate method used by Doherty and Nickle,[4] which they have discussed fully. It is then found that the decrement factor for the coil group is

$$\sigma_r = \frac{\omega r_s}{\sqrt{X_{SD}' X_{SQ}'}} \tag{23}$$

where r_s is the resistance of the shorted coils, and that for the field is

$$\sigma_f = \frac{X_{SD} + \sqrt{X_{SD}' X_{SQ}'}}{X_{SD}' + \sqrt{X_{SD}' X_{SQ}'}} \cdot \frac{R_d}{L_d} \tag{24}$$

when R_d is the total resistance of the field circuit.

Experimental Confirmation of Theoretical Results

To verify the theory, experimental measurements were made of the short-circuit current in a single coil of a 125-horsepower, 440-volt, 60-cycle, 900-rpm, three-phase, synchronous motor. This machine had a full-pitch armature winding, no amortisseur on the rotor, and was a specially built laboratory machine with the leads to the armature coils brought out to a terminal board, making each coil accessible for measurements. The measured values of the reactances and resistances of the machine are given in table I.

Table I. Measured Reactances* and Resistances of Test Machine

X_d =	1.520 ohms	X_D =	1.050 ohms
X_d' =	0.445 ohm	X_D' =	0.266 ohm
$X_q = X_q'$ =	1.205 ohms	$X_Q = X_Q'$ =	0.970 ohm
X_0 = 0.237 ohm			
X_{md} = 37.3 ohms			
r_a = 0.048 ohm at 25 C (line to neutral)			
R_d = 23.5 ohms at 25 C			

* Measured by static test method.

Using the equations that have been developed, it is found that for a single armature coil of the machine,

$K_s = 0.0434$
$X_{SD} = X_{SQ} = X_{SQ}' = 0.0126$ ohm
$X_{SD}' = 0.01109$ ohm

The short-circuit current was measured by taking the voltage drop across a 0.000243-ohm, non-inductive shunt in series with the coil. The wave form of the current was obtained from an oscillogram of this voltage, and the magnitudes of the sustained harmonic components were measured with a vacuum-tube harmonic analyzer.

The coil used in the test was in the center of phase A, so that $\beta = 0$. The current was calculated analytically and checked experimentally for short circuits occurring under two different operating conditions, one when the machine was loaded, and one at no load. Both tests were made at reduced voltage to eliminate the effect of saturation as far as possible.

For the short circuit under load, the machine was operating with a pure resistive load of 2.45 ohms per phase and a field current of 0.992 ampere. The short circuit occurred at $\theta_0 = 215°$. The calculated current for the short-circuited coil was

$$i_s = -164.0\cos(\theta - 17.28°) - 5.13\times\cos(3\theta - 23.16°) - 0.161\times\cos(5\theta - 23.16°) - \ldots - e^{-0.0128\omega t}[4.80\times\cos(\theta + 19.85°) + 0.116\times\cos(3\theta + 13.38°) + \ldots] - e^{-0.1987\omega t}[163.3 + 10.27\cos 2\theta + 0.324\cos 4\theta + \ldots]$$

where $215° < \theta$ and $\omega t = (\theta - \theta_0)$ in radians. In table II the magnitudes of the harmonics of the calculated sustained current are compared with the actual values as measured with a harmonic analyzer.

The short-circuit at no load occurred at $\theta_0 = 180°$ and the field current was 0.988 ampere. The calculated current is

$$i_s = -185.5\cos\theta - 5.85\cos 3\theta - 0.184\times\cos 5\theta - \ldots - e^{-0.1987\omega t}[191.5 + 12.06\cos 2\theta + 0.38\times\cos 4\theta + \ldots]$$

where $180° < \theta$ and $\omega t = (\theta - \theta_0)$ in radians. The magnitude of the sustained harmonics of the calculated and measured currents are compared in table II.

Considering only the fundamental components of sustained current, the data in table II show that the calculated and measured values agree very closely. The analytical and experimental results for the higher harmonics, however, do not agree. This is probably due in large part to the fact that the higher harmonics of mutual linkages between the coil and the other machine circuits were neglected in the analysis. While the voltages due to higher harmonics of flux are ordinarily small in the complete phase due to the effects of fractional pitch and distributed windings, they may be much more important in one or two coils. To neglect these harmonics of flux, therefore, may introduce considerable error in the higher harmonics of current in the short-circuited coils. As they have little effect on the fundamental voltage, however, they may be disregarded in determining the fundamental component of current.

Table II. Comparisons of Peak Values* of Harmonics of Sustained Current in a Single Coil

	Fundamental	Third	Fifth
Machine loaded			
Calculated	164.0	5.13	0.161
Measured	165.5	29.1	6.69
No load			
Calculated	185.5	5.85	0.184
Measured	190.7	30.85	8.49

* All values are given in amperes.

Oscillograms were made of the short-circuit current, and these were compared with a graphical plot of the calculated current. The agreement between the calculated and test results was fairly good, both during the transient period and after the transient components had died out. The effect of the larger values of the harmonics in the actual current was noticeable, however, the actual waves being slightly more peaked than those which were calculated.

Had the test machine been operated at higher flux densities, the effect of saturation would probably have been noticeable. As pointed out by Doherty and Nickle, this would not prevent the use of the results of the theoretical analysis, as the effect of saturation may be taken into account by proper shading of the machine constants.

Appendix I

Inductance Equations

Expressions for the inductances of the field and armature circuits may be obtained by application of the extension of Blondel's method previously mentioned. With the assumptions that have been made, only the fundamental component of magnetomotive force need be considered in obtaining the mutual linkages due to any machine circuit. The procedure is to resolve this space sinusoid into two components, one in the direct axis and one in the quadrature axis, determine the corresponding fundamental linkages due to each component acting separately, and combine these linkages to get the resultant. The fundamental linkages in any other circuit of the machine per unit current in the exciting circuit are equal to the mutual inductance between the two. That portion that is due to the space fundamental of air gap flux is the inductance of armature reaction, and the remainder, which is due to flux in the slots and end windings, is leakage inductance.

Self-Inductance of Armature Reaction of a Complete Phase Winding

Let the flux density per unit magnetomotive force at the armature surface be represented by the even harmonics series[3]

$$P = P_0 + P_2\cos 2\lambda + P_4\cos 4\lambda + \ldots \quad (25)$$

The fundamental component of the linkages with the complete phase A winding of the air-gap flux due to the fundamental component of magnetomotive force of phase A may be expressed as

$$\psi_{aa} = i_a\{L_{AD}\cos^2\theta + L_{AQ}\sin^2\theta\} \quad (26)$$

where

$$L_{AD} = 3.2DlI(yN_cK_dK_p)^2\{P_0 + (1/4)P_2\} \quad (27)$$

$$L_{AQ} = 3.2DlI(yN_cK_dK_p)^2\{P_0 - (1/4)P_2\} \quad (28)$$

are the static inductances of armature reaction for one phase.

Mutual Inductances Between Coil Group and Phase and Field Windings

If the space fundamental of magnetomotive force for the coil group is considered, it may easily be shown that the linkages of armature reaction in phase A due to the current in the coil group are

$$\psi_{aa} = i_aK_s\{L_{AD}\cos(\theta - \beta)\cos\theta + L_{AQ}\times\sin(\theta - \beta)\sin\theta\} \quad (29)$$

where

$$K_s = \frac{sK_{ds}}{pyK_d} \quad (30)$$

and s is the number of coils in the group, y the slots per phase per pole, p the number of poles, K_d the phase belt distribution factor, and K_{ds} the distribution factor for the s coils; that is, sK_{ds} is the ratio of the fundamental of magnetomotive force for the coil group to that for a single coil. The corresponding linkages in phase B are obtained by replacing $\cos\theta$ and $\sin\theta$ by $\cos(\theta - 120°)$ and $\sin(\theta - 120°)$ respectively, and those for phase C may be obtained by using $(\theta - 240°)$ instead of $(\theta - 120°)$. The linkages per unit current in these expressions are equal to the mutual inductances of armature reaction between the phase windings and the coil group. The corresponding mutual leakage linkages will have the same form except that, being independent of rotor position, they will be the same for direct and quadrature axes. These mutual leakage inductances are $K_sL_l\cos\beta$, $K_s2L_{lm}\times\cos(\beta - 120°)$, and $K_s2L_{lm}\cos(\beta - 240°)$ for phases A, B, and C respectively. Adding these components to those due to armature reaction, it is found that the mutual inductance between the coil group and phase A is

$$L_{aa} = K_s\{L_D\cos(\theta - \beta)\cos\theta + L_Q\times\sin(\theta - \beta)\sin\theta\} \quad (31)$$

The corresponding expression for the mutual

inductance between the coil group and phase B is

$$L_{Bs}=K_s\{(L_D-L_0)\cos(\theta-\beta)\cos(\theta-120°)+(L_Q-L_0)\sin(\theta-\beta)\sin(\theta-120°)\} \quad (32)$$

and that for phase C is similar to equation 32 with $(\theta-240°)$ instead of $(\theta-120°)$.

The procedure followed in the preceding paragraph may be used to obtain the mutual inductances between the coil group and the field windings. These inductances are then found to be

$$M_{sd}=K_sM_d\cos(\theta-\beta) \quad (33)$$

$$M_{sq}=K_sM_q\sin(\theta-\beta) \quad (34)$$

It should be noted that all of the mutual inductances for the coil group are expressed as the product of the constant K_s and the inductances of the machine per phase.

Self Inductance of a Coil Group

Although space harmonics of magnetomotive force cannot appear in the complete phase winding of an ideal machine, they must be considered in obtaining an expression for the self inductance of a coil group. In the work that follows, therefore, the complete magnetomotive force of the coil group will be considered.

As the inductance of a coil group is a function of the self and mutual inductances for the individual coils in the group, the first step in this analysis will be to develop an expression for the self inductance of a single coil. The next step will be to obtain a general expression for the mutual inductance between two coils. These self and mutual inductances may then be combined to obtain the total self inductance of the coil group.

Assuming that the current i_t in a single coil of N_c turns is distributed in a line at the armature surface and that the iron has infinite permeability, the magnetomotive force distribution of the coil over the coil span ρ is a square-topped wave of magnitude

$$A_1=(1-\rho/p\pi)(0.4\pi N_ci_t) \quad (35)$$

If the relation between the flux density and magnetomotive force is expressed by equation 25, the linkages, with the coil, of the air-gap flux due to this magnetomotive force may be shown to be

$$\psi_{ss}=[(p-\rho/\pi)\{\pi^3/8(pyK_dK_p)^2\}]\times\{(\rho/2\pi)(L_{AD}+L_{AQ})+(1/\pi)\times(L_{AD}-L_{AQ})\sin\rho\cos2(\theta-\beta)\} \quad (36)$$

when the small higher harmonics are neglected.

Since the path of the leakage flux in the slots and end windings is practically the same for a single coil and a complete phase and since there are $1/py$ as many turns for the single coil as for the phase winding, the ratio of the leakage linkages for the coil to those for the phase is approximately $1/(py)^2$. As indicated by equations 26 and 36 this is much smaller than the corresponding ratio for the linkages due to air-gap flux. The leakage component is, therefore, only a small percentage of the total linkages of the coil. Since $2L_{2m}$ is also very small in comparison to $(^1/_2)(L_{AD}+L_{AQ})$, the assumption will be made that the total linkages of the coil can be expressed in a form similar to equation 36 with

$$(^1/_2)(L_D+L_Q)-L_0=(^1/_2)(L_{AD}+L_{AQ})+2L_{2m}$$

substituted for $(^1/_2)(L_{AD}+L_{AQ})$. Although this assumption may introduce considerable error in the leakage linkages added, it will make only a small discrepancy in the total linkages, and the equation may be put in a much more convenient form for calculation. The total self inductance of a single coil is then

$$L_{ss}=L_{SD}\cos^2(\theta-\beta)+L_{SQ}\sin^2(\theta-\beta) \quad (37)$$

where

$$L_{SD}=[(p-\rho/\pi)\{\pi^3/8(pyK_dK_p)^2\}]\times[(\rho/\pi)\{(^1/_2)(L_D+L_Q)-L_0\}+(1/\pi)(L_D-L_Q)\sin\rho] \quad (38)$$

$$L_{SQ}=[(p-\rho/\pi)\{\pi^3/8(pyK_dK_p)^2\}]\times[(\rho/\pi)\{(^1/_2)(L_D+L_Q)-L_0\}-(1/\pi)(L_D-L_Q)\sin\rho] \quad (39)$$

The magnetomotive force distribution of the single coil over the armature outside the coil span will be a square-topped wave of magnitude

$$A_2=-(\rho/p\pi)(0.4\pi N_ci_t) \quad (40)$$

Using equations 27 and 28 and making the same assumptions regarding leakage linkages that were made in deriving equation 37, it may be shown that the mutual inductance between two coils separated a small angle Δ is approximately

$$L_{ss_2}=\{(p-\rho/\pi)(\pi^3/8)/(pyK_dK_p)^2\}\times[\{\rho/\pi-\rho\Delta/(p\pi-\rho)\}\{(^1/_2)(L_D+L_Q)-L_0\}+(1/\pi)\cos\Delta\sin(\rho-\Delta)\times\{(L_D-L_Q)\cos2(\theta-\beta)\}] \quad (41)$$

The total self inductance of a group of coils may be obtained from the relationship

$$L_{ss}=L_{11}+L_{22}+L_{33}+\ldots+2(L_{12}+L_{13}+L_{23}+\ldots) \quad (42)$$

where L_{11}, L_{22}, . . . are the self inductances of each coil given by equation 37 and L_{12}, L_{13}, . . . are the mutual inductances between coils 1 and 2, 1 and 3, etc., as given by equation 41. It is apparent that the total self inductances of the coil group can be put in the form of equation 37 if L_{SD} and L_{SQ} are given the proper values. Equation 37, therefore, is a general expression for the total self inductance of a group of armature coils whether the group consists of one, two, or more coils.

Transient Inductances

The transient inductances L_{SD}' and L_{SQ}' are defined by

$$L_{SD}'=L_{SD}-K_s^2(M_d^2/L_d) \quad (43)$$

$$L_{SQ}'=L_{SQ}-K_s^2(M_q^2/L_q) \quad (44)$$

The inductances L_d', L_q', L_D', and L_Q' correspond to the transient reactances X_d', X_q', X_D', and X_Q' as ordinarily defined in the literature.

Appendix II

Linkage and Voltage Equations

The armature and field linkages for an ideal synchronous machine under normal conditions have been given by Park.[1,2] Following his analysis, it may be shown that if

$$\psi_d=(^3/_2)(L_d+L)i_d+M_dI_d \quad (45)$$

$$\psi_q=(^3/_2)(L_q+L)i_q+M_qi_q \quad (46)$$

then the following voltage equations may be obtained:

$$-\frac{d\psi_d}{dt}-\psi_q\frac{d\theta}{dt}=\frac{2}{3}ri_d \quad (47)$$

$$-\frac{d\psi_q}{dt}+\psi_d\frac{d\theta}{dt}=\frac{2}{3}ri_q \quad (48)$$

where r is the combined resistance of one phase of the machine and load.

When the machine contains another circuit of a group of short-circuited coils, the linkage equations must be modified to include the effect of the additional current in the faulty coils. This may be done by making use of the expressions for the mutual inductances between the coil group and the phase and field windings.

It is convenient to consider the magnetomotive force of the portion of the phase A winding that is outside the faulty coils as the difference between that due to a current i_s in the complete phase winding and that due to the coil group carrying the same current i_s. Similarly, the linkages in this portion of the phase A winding due to other currents may be obtained by subtracting the linkages in the faulty coils from those in the complete phase.

When the inductance equations developed in appendix I are used, the modified forms of equations 45 and 46 become

$$\psi_d=(^3/_2)(L_d+L)i_d+K_sL_D(i_s-i_a)\times\cos(\theta-\beta)+M_dI_d \quad (49)$$

$$\psi_q=(^3/_2)(L_q+L)i_q+K_sL_Q(i_s-i_a)\times\sin(\theta-\beta)+M_qI_q \quad (50)$$

It may then be shown that, to a close approximation, the voltage equations 47 and 48 are applicable to the short-circuited machine when ψ_d and ψ_q have the values given in equations 49 and 50.

Appendix III

Short-Circuit Currents Assuming Load Currents Constant

At the instant of short circuit, $\theta=\theta_0$, $i_d=i_{d0}$, $i_q=i_{q0}$, $I_d=I_{d0}$, and $I_q=0$. Applying the constant linkage theorem, the linkages in the coil group and the field windings are

$$K_s\{(^3/_2)L_di_d+M_dI_d\}\cos(\theta-\beta)+K_s\{(^3/_2)L_qi_q+M_qI_q\}\sin(\theta-\beta)+\{L_{SD}\cos^2(\theta-\beta)+L_{SQ}\sin^2(\theta-\beta)\}(i_s-i_a)=K_s\{(^3/_2)L_di_{d0}+M_dI_{d0}\}\cos(\theta_0-\beta)+K_s\{(^3/_2)L_qi_{q0}\}\sin(\theta_0-\beta) \quad (51)$$

$$M_di_d+K_sM_d(i_s-i_a)\cos(\theta-\beta)+L_dI_d=M_di_{d0}+L_dI_{d0} \quad (52)$$

$$M_qi_q+K_s(i_s-i_a)\sin(\theta-\beta)+L_qI_q=0 \quad (53)$$

In accordance with the method of analysis that has been outlined, the first approximation to the solution is obtained by assuming

that $i_d = i_{d0}$ and $i_q = i_{q0}$ remain constant. Then a simultaneous solution of equations 51, 52, and 53 gives

$$(i_a - i_a) = \frac{\begin{matrix} e_{SD}\{\cos(\theta_0-\beta) - \cos(\theta-\beta)\} + \\ e_{SQ}\{\sin(\theta_0-\beta) - \sin(\theta-\beta)\} \end{matrix}}{\begin{matrix} (1/4)(X_{SD}' + X_{SQ}') + \\ (1/4)(X_{SD}' - X_{SQ}')\cos 2(\theta-\beta) \end{matrix}} \quad (54)$$

$$I_d = I_{d0} - \frac{X_{SD} - X_{SD}'}{K_s X_{md}}(i_a - i_a)\cos(\theta-\beta) \quad (55)$$

where e_{SD} and e_{SQ} are defined by equations 11 and 12. These may also be expressed as

$$(i_a - i_a) = i' + i'' \quad (56)$$

$$I_d = I_d' + I_d'' \quad (57)$$

where i' and i'' are given by equations 9 and 10 and I_d' and I_d'' are

$$I_d' = I_{d0} + \frac{X_{SD} - X_{SD}'}{K_s X_{md}} \frac{e_{SD}}{X_{SD}' + \sqrt{X_{SD}' X_{SQ}'}} +$$

$$\frac{X_{SD} - X_{SD}'}{K_s X_{md}}\left[\frac{e_{SD}(1-B)^2}{2\sqrt{X_{SD}' X_{SQ}'}}\{\cos 2(\theta-\beta) + B\cos 4(\theta-\beta) + \ldots\} + \frac{e_{SQ}(1-B^2)}{2\sqrt{X_{SD}' X_{SQ}'}} \times \{\sin 2(\theta-\beta) + B\sin 4(\theta-\beta) + \ldots\}\right] \quad (58)$$

$$I_d'' = \frac{(X_{SD} - X_{SD}')(1+B)}{2K_s X_{md}\sqrt{X_{SD}' X_{SQ}'}}\{e_{SD}\cos(\theta_0-\beta) + e_{SQ}\sin(\theta_0-\beta)\}[\cos(\theta-\beta) + B\cos 3(\theta_0-\beta) + \ldots] \quad (59)$$

The average field current is

$$I_d(\text{average}) = I_{d0} + \frac{X_{SD} - X_{SD}'}{K_s X_{md}} \frac{e_{SD}}{X_{SD}' + \sqrt{X_{SD}' X_{SQ}'}} = G_0 I_{d0} \quad (60)$$

where G_0 is the value of G_1 obtained from equation 22 by setting $i_{q1} = i_{q0}$.

The component of field current, I_d'', contains the odd harmonics and is due to the unidirectional component and even harmonics of the current $(i_a - i_a)$ to which it is directly proportional. It therefore decays to zero according to the decrement factor σ_s.

The current I_d', containing the unidirectional component and even harmonics, must have an average sustained value I_{d0} since it is supported entirely by the exciter voltage. Its sustained value is therefore $(1/G_0)i_d'$. The remainder $(1-1/G_0)I_d'$, is transient in character and, being proportional to the average field current, decays at a rate fixed by σ_f.

Separated into sustained and transient components and with the decrement factors applied, the field current at any instant after the short circuit is

$$I_d = (1/G_0)I_d' + (1-1/G_0)I_d' e^{-\sigma_f t} + I_d'' e^{-\sigma_s t} \quad (61)$$

Appendix IV

Short-Circuit Currents Assuming Change in Load Currents

A second approximation to the solution for the short-circuit current is obtained by assuming that i_d and i_q have average values given by equations 6 and 7. It will first be necessary, however, to develop expressions for the currents i_{d1} and i_{q1}.

The currents i_{d1} and i_{q1} may be obtained by use of the voltage equations given in appendix II. Considering only average values, $d\psi_d/dt = d\psi_q/dt = 0$. The average value of $(i_a - i_a)\cos(\theta-\beta)$ is $(1/2)I_1\cos\alpha_1$ and that of $(i_a - i_a)\sin(\theta-\beta)$ is $(1/2)I_1\sin\alpha_1$, where I_1 and α_1 are defined by equations 17 and 18. Likewise, the average value of I_d is I_{d0} and the average of $I_q = 0$. Then from equations 47, 48, 49, and 50,

$$(3/2)(X_q + X_L)i_{q1} + (1/2)K_s X_Q I_1 \sin\alpha_1 + (3/2)r i_{q1} = 0 \quad (62)$$

$$(3/2)(X_q + X_L)i_{d1} + (1/2)K_s X_D I_1 \cos\alpha_1 - (3/2)r i_{q1} = -X_{md} I_{d0} \quad (63)$$

These may be solved simultaneously to obtain the currents i_{d1} and i_{q1}. The results are given in equations 19 and 20.

With currents i_d and i_q given by equations 6 and 7, the linkage equations for the short-circuited coils and field windings may be obtained. Following the same procedure as before, these may be solved for the initial currents. When the short-circuit current is separated into its sustained and transient components and the proper decrements are applied, the second approximation to the solution is that given by equation 21.

Nomenclature

i_a, i_b, i_c = currents in phases A, B, and C

i_s = current in short-circuited coil group

I_d = current in main field winding

I_q = current in field winding in quadrature axis

K_d, K_p = distribution and pitch factors for armature phase winding

K_{d0} = distribution factor for the group of s coils as discussed following equation 30

$K_s = (sK_{d0}/pyK_d)$ is a constant

L_D, L_Q = total static inductances, single phase, in the direct and quadrature axes, respectively. These correspond to the commonly used reactances, X_D and X_Q

L_d, L_q = total three phase, line to neutral inductances in the direct and quadrature axes corresponding to the synchronous reactances X_d and X_q

$L_0 = (L_l - 2L_{lm})$ = zero sequence inductance corresponding to X_0

L_l, L_{lm} = self and mutual leakage inductances per phase

L_{SD}, L_{SQ} = inductances of coil group in the direct and quadrature axes. See appendix I

L = load inductance per phase corresponding to X_L

M_q = maximum mutual inductance per phase between quadrature axis field winding and armature

M_d = maximum mutual inductance per phase between main field and armature

s = number of coils in short-circuited coils

X_d, X_q, X_d', X_q' = usual three phase, line to neutral, synchronous and transient reactances for the direct and quadrature axes

$X_{md} = \omega M_d$

X_D, X_Q, X_D' X_Q', = usual static single phase and transient reactances in the direct and quadrature axes

X_{SD}, X_{SQ} = reactances corresponding to L_{SD}, L_{SQ}

$X_L = \omega L$ = reactance of load per phase

β = angular displacement, in electrical radians, of the axis of the group of s short-circuited coils from that of phase A

ρ = coil pitch in electrical radians

θ = angular displacement of direct axis from that of phase A, measured in electrical radians

σ_f = decrement factor of main field, defined by equation 23

σ_s = decrement factor of short-circuited coils, defined by equation 24

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Transient Overspeeding of Induction Motors

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Synopsis: A transient swing above synchronous speed has been observed when a certain standard squirrel cage induction motor was started without load. This paper presents an explanation of the phenomenon based on the frequency modulation of the power supply caused by the rapid variation of the power taken from the line. Mathematical relations are developed and applied to the operating conditions of this motor. The agreement of the mathematical and test curves indicates that the explanation is basically correct although some secondary effects, not considered, may be present.

A TRUE induction motor cannot, of itself, operate at or above synchronous speed. The torque developed by this type of motor passes through zero at synchronous speed. It should, therefore, never be able to send the motor above that speed. Yet, in making some acceleration tests, a certain motor was consistently found to go above synchronous speed for a few cycles each time it was started.

This motor was from a standard line of squirrel cage induction motors. It had a cast aluminum rotor with deep, narrow slots. There were no salient-pole structures on the rotor, and, further, the rotor bars were skewed so that there was no tendency for the rotor to lock into synchronism. After the motor was up to speed and had settled down, the slip at no load became constant at less than 0.1 per cent.

The tests in which this behavior was observed were similar to those described in a previous paper.[1] A bakelite disc having 500 divisions accurately engraved around the periphery was mounted on the motor shaft. This disc was illuminated by light pulses from a stroboscopic lamp flashing 60 times per second, and the disc's position was photographically recorded at each flash. The motor was reversed on the line and readings were taken as the motor speed dropped from full speed in one direction to zero and then came back up to full speed in the opposite direction. Velocities were calculated by taking position differences, and accelerations were calculated by taking velocity differences. Since the friction forces were very small the entire torque of the motor was used in producing accelerations. The accelerations observed were converted to torques and plotted against speed in figure 1. Figure 2 shows a section of the velocity versus time curve for the same test. In this test the motor was operated at rated voltage. Due to the high torques developed and the low inertia of the rotor, the motor dropped from full speed in one direction to zero and returned to full speed in the opposite direction in a little over one-half second.

The curve of figure 2 shows that the motor passed through synchronous speed about 35.5 cycles after the test was started, and that it rose almost two per cent above synchronous speed on the first over-swing. A second over-swing was recorded and a third one indicated. Reference to the torque curve of figure 1 shows that the torque developed was practically equal to full-load torque as the motor passed through synchronous speed the first time.

The reason for this peculiar behavior was first qualitatively described as follows. The input to the motor had both power and lagging components. The power input to the motor was approximately proportional to the torque developed. The curve of figure 1 would indicate that during the first part of the test the power input was relatively constant. After passing the maximum torque at about 85% of synchronous speed the power taken from the lines dropped very rapidly. The lagging component of the line current, however, certainly did not vary in the same way. A more gradual change of this component would be expected. The power component would reverse if the motor changed from motor to generator action. Such reversal would not occur in the magnetizing component. From full load to no load the lagging component should be nearly constant and therefore cause constant IR and IX drops. Since it is the rapid variation of these impedance drops which is important and not their magnitudes the effects of the lagging component may be neglected. The power was supplied from a transformer bank connected to a 4,000 volt system. The bank had an appreciable reactance. Neglecting the resistance of the bank and the lagging component of the motor current, the vector diagram would be as indicated in figure 3. In this diagram E_1 represents the transformer primary voltage vector which may be taken as constant in magnitude and rotating at a constant velocity ω_1. E_2 is the motor-voltage vector and IX is the reactance drop in the transformer due to the power component of the motor current. As long as the power component is constant the vector E_2 must rotate at the same speed as the vector E_1, although lagging behind it. If the power component decreases the impedance drop must decrease and the vector E_2 must catch up with vector E_1. Therefore during this transient period the vector must rotate at a velocity ω_2 greater than that corresponding to the normal line frequency. With a frequency greater than 60 cycles impressed on the motor terminals, even if only for a few cycles, the motor may attain a speed greater than the 60 cycle synchronous speed if very lightly loaded.

A more quantitative analysis following the above ideas has indicated that this reasoning is correct. The motor on which the tests were made is no longer available and accurate measurements of its constants had not been made. Approximate values of some of these constants had been determined and the others may be estimated accurately enough for present purposes. All values used are thought to be within 3% of the correct values except

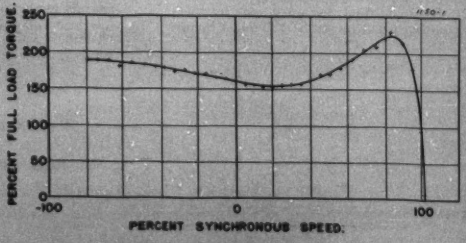

Figure 1. Speed-torque curve for a 15-horsepower four-pole squirrel-cage motor

Curve was determined under transient conditions for rapid acceleration under no load

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The data used in this paper were obtained by C. N. Williamson, a former student of the University of California, now with the U. S. Navy engineering department.

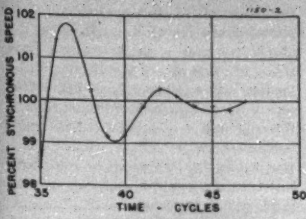

Figure 2. Section of velocity-versus-time curve for same test as figure 1

the full load slip. The full load slip was not determined but the motor manufacturer was consulted before assigning the value used.

Near synchronous speed the torque developed is proportional to the slip, and this torque will all be used in accelerating the rotor if the friction forces are negligible.

$$T = K_1 S = \frac{WR^2}{g} \times \frac{d\omega}{dt} \tag{1}$$

Where S is the slip and ω is the angular velocity of the rotor in radians per second. The full load torque of the motor was 45 pound-feet, and the full load slip was about 2.0 per cent. Therefore the constant K_1 was 45/0.020 or 2,250. The inertia of the rotor, coupling, and disc was 4.0 pound-feet-squared.

From figure 3

$$\omega_2 = \omega_1 - \frac{d\alpha}{dt} \tag{2}$$

The line frequency was 60 cycles per second so that $\omega_1 = 2\pi 60 = 377$. Equation 2 is on a 2-pole basis while equation 1 is for a general p-pole machine. Converting equation 1 to the 2-pole basis it becomes

$$T' = \frac{2K_1}{p} S = \frac{4WR^2}{p^2 g} \frac{d\omega'}{dt} \tag{3}$$

The slip which must be used in these relations depends upon the angular velocity of the rotor and the frequency applied to the motor terminals, and is not the apparent slip based on the nominal line frequency. Therefore

$$S = \frac{\omega_2 - \omega'}{\omega_2} \tag{4}$$

From this

$$\omega_2 = \frac{\omega'}{1 - S} \tag{5}$$

Combining (2) and (5)

$$\frac{\omega'}{1-S} = \omega_1 - \frac{d\alpha}{dt} \tag{6}$$

But α is a function of the slip. In the region of interest where the slip is small the lagging component of motor current is nearly constant while the power component is directly proportional to the slip. The angle α therefore varies directly with the slip in this region.

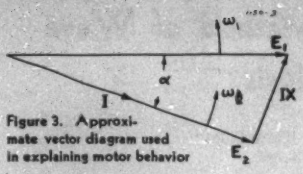

Figure 3. Approximate vector diagram used in explaining motor behavior

$$\alpha = K_2 S \tag{7}$$

The reactance which must be used in computing α is not just the transformer and lead reactance. The motor reactance must be included in this total and will usually be the largest item. For full load the reactance drop was estimated to be 20% of E_1. The angle α was therefore 11.5° or 0.20 radian for 2% slip, and the constant K_2 equal to 10.

Combining equations 6 and 7

$$\omega' = (1-S)\left(\omega_1 - K_2 \frac{dS}{dt}\right) \tag{8}$$

This value of ω' may be substituted in equation 3 giving

$$\frac{2K_1 S}{p} = \frac{4WR^2}{p^2 g} \frac{d}{dt}(1-S)\left(\omega_1 - K_2 \frac{dS}{dt}\right) \tag{9}$$

Differentiating after multiplying by $\frac{p^2 g}{4WR^2}$

$$\frac{K_1 pg}{2WR^2} S = (1-S)\left(-K_2 \frac{d^2S}{dt^2}\right) - \left(\omega_1 - K_2 \frac{dS}{dt}\right)\left(\frac{dS}{dt}\right) \tag{10}$$

Rearranging and dividing by K_2

$$(1-S)\frac{d^2S}{dt^2} + \left(\frac{\omega_1}{K_2} - \frac{dS}{dt}\right)\frac{dS}{dt} + \frac{K_1 pg}{2K_2 WR^2} S = 0 \tag{11}$$

Since the slip is very small in the region of interest the term $(1-S)$ is nearly equal to 1. Also the term $\left(\frac{\omega_1}{K_2} - \frac{dS}{dt}\right)$ is not very different from $\frac{\omega_1}{K_2}$. In figure 2, $\frac{dS}{dt}$ has a value of about 1.8 as the motor passes through synchronism the first time. The tests were made on a 60 cycle supply so that $\frac{\omega_1}{K_2} = 37.7$. Making these approximations, equation 11 becomes

$$\frac{d^2S}{dt^2} + \frac{\omega_1}{K_2}\frac{dS}{dt} + \frac{K_1 pg}{2K_2 WR^2} S = 0 \tag{12}$$

The roots of this equation are

$$D = -\frac{\omega_1}{2K_2} + \sqrt{\frac{\omega_1^2}{4K_2^2} - \frac{K_1 pg}{2K_2 WR^2}} \tag{13}$$

Substituting the numerical values corresponding to the tests in this equation

$$D = -18.8 + \sqrt{355 - 3{,}622} = (-18.8 + j57.2)(-18.8 - j57.2) \tag{14}$$

By choosing zero time as the first time the motor passes through synchronous speed or zero slip, and further making the slopes of the two curves the same at this point, the slip equation becomes

$$S = -0.0315 e^{-18.8t} \sin 57.2t \tag{15}$$

This is a damped oscillation having a frequency of 9.1 cycles per second. The frequency of the damped oscillation shown in figure 2 is about 10 cycles per second. The damping is nearly the same in the two cases. A plot of equation 15 is shown in figure 4. The test curve of figure 2 is replotted for comparison. Negative values of slip have been plotted above the axis and the ordinate scaled in terms of synchronous speed so that the curve will appear the same as figure 2. The discrepancies between the test results and equation 15 are due to several causes. First the determination of the constants of the motor were not as accurate as desired. Second the setting up and solution of the differential equation involved approximations. Third the motor was changing speed so rapidly that one might expect that the functions K_1 and K_2, called constants, might not be strictly constant, and their numerical values under these transient conditions might be different from values determined by steady state tests.

Equation 13 indicates that oscillations will be present when the quantity under the radical is negative. This condition exists when

$$\frac{K_1 K_2 p}{WR^2} > \frac{\omega_1^2}{2g} \tag{16}$$

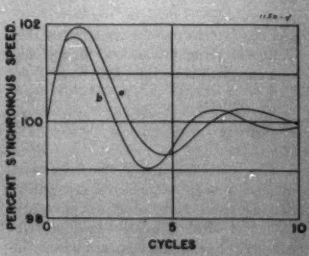

Figure 4

(a) $100\,(1-S) = 100 + 3.15 e^{-18.8t} \sin 57.2t$

(b) Experimental curve shown in figure 2

A Cathode-Ray Method of Wave Analysis

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Synopsis: Complex periodic functions, when transformed into a corresponding voltage wave, may be analyzed with the use of a cathode ray oscillograph. The complex wave is represented upon the fluorescent screen of the cathode ray tube by a vertical displacement at the same time that a sinusoidal horizontal oscillation exists. If the frequency of the sinusoidal oscillation bears an integral relation to the fundamental frequency of the complex wave, a Lissajous figure is viewed on the screen. The areas of these Lissajous figures are directly related to the coefficients of the Fourier series of the complex wave. The area is determined by measuring a photograph of the figure using a polar planimeter. The method is based on the theory developed by Mr. L. W. Chubb in connection with the Chubb Polar Analyzer.[4] Advantages of the method are that it is quick and convenient, only standard laboratory equipment is necessary, and with special equipment, it promises to make possible the analysis of ultrahigh frequency waves.

PERIODIC waves, such as the vibration of mechanical bodies or the variation of current and voltage in electric circuits, are often complex. In electric circuits, sinusoidally varying functions usually give the most satisfactory operation. Calculations are much easier, values may be expressed graphically in vector diagrams, and vector equations may be used. The same is true of mechanical vibration. Hence, in order to handle complex waves conveniently, it is desirable that they be separated into their sinusoidal components. It is the purpose of this paper to describe and explain a new method of wave analysis using a cathode ray oscillograph. The underlying theory is not new, but the method is thought to be faster and the results more complete than other methods of wave analysis using ordinary laboratory equipment. It is hoped that this method will prove useful in other laboratories.

Application of Lissajous Figures to Wave Analysis

The electron beam in a cathode ray tube is deflected by electrostatic forces. If the beam be deflected in one direction by an alternating voltage, and at the same time by another voltage in a direction at right angles to the first, the resulting position of the beam at any instant of time is a function of both voltages. If one frequency is an even multiple of the other, the resulting pattern upon the screen is a Lissajous figure.

In order to begin a study of Lissajous figures, a simple Lissajous figure is shown in figure 1. The two functions to be compounded are $f(\theta)=A_1 \sin \theta$, and $g(\theta)=A_2 \sin (\theta+\alpha)$. The Lissajous figure is an ellipse with a maximum vertical dimension of $2A_2$ and a maximum horizontal dimension of $2A_1$. If $\alpha=0$, the ellipse becomes a single straight line; if $\alpha=90°$, one axis of the ellipse will be vertical and equal to $2A_2$, and the other axis will be horizontal and equal to $2A_1$; if $\alpha=90°$ and $A_1=A_2$, the Lissajous figure becomes a circle. More complex Lissajous figures are obtained if either or both functions are complex. In this case the fundamental frequencies of the functions must be the same or bear an integral ratio to each other.

The Fourier series for a complex function may be expressed as follows:

$$f(\theta)=A_0+C_1 \sin (\theta+\theta_1)+C_2 \sin 2(\theta+\theta_2)+\ldots+C_n \sin n(\theta+\theta_n)+\ldots \quad (1)$$

where θ is a function of time equal to $2\pi ft$. However, due to the difficulty of using the harmonics in their various phase positions, each harmonic is usually resolved into two quadrature components thus:

$$f(\theta)=A_0+A_1 \sin \theta+B_1 \cos \theta+A_2 \sin 2\theta+B_2 \times \cos 2\theta+\ldots+A_n \sin n\theta+B_n \cos n\theta+\ldots \quad (2)$$

As a result, wherever complex periodic waves are encountered they are usually resolved into their harmonic components in order to permit a simpler mathematical treatment. The process of harmonic analysis, then, reduces merely to a problem of evaluating the coefficients A_0, A_1, B_1, etc., in the above series. This can be done in a great number of ways.

Experiments have been conducted in the laboratories of the A. & M. College of Texas using a low voltage cathode ray oscillograph for wave analysis. The complex wave is applied to the horizontal plates which give the cathode beam a vertical displacement. This pair of plates will be referred to hereafter as the horizontal plates, and the other pair of plates as the vertical plates. Ordinarily

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1. For all numbered references, see list at end of paper.

For K_1 and K_2 may be substituted their values in terms of full-load torque, slip, and angular phase shift.

$$\frac{Tap}{WR^2S^2} > \frac{\omega_1^2}{2g} \quad (17)$$

This relation indicates that overspeeding may be reduced by increasing the WR^2 of a machine. Large machines have large values of WR^2 but also produce large torques. The inertia constant usually increases more rapidly than the torque, as the machine size is increased, so that these larger motors should show less tendency to over speed. The most important factor is the full-load slip since it occurs in the function as a squared term. Motors with low full-load slip should have much greater tendencies to overspeed than high-slip motors. Operation at reduced voltage would decrease this tendency by changing the relation between the torque, slip, and angle.

Various acceleration methods have been considered as a means of determining the speed-torque curves of induction motors. The above analysis indicates that precautions must be taken to avoid conditions similar to those found in these tests if accurate results are to be obtained. However the errors involved are appreciable only near synchronous speed where the frequency change represents a large percentage of the rotor frequency. Where acceleration methods are used to determine only the low-speed part of the curve, errors due to this frequency modulation should not be important.

Reference

1. SOME ACCELERATION TESTS ON LARGE SYNCHRONOUS PUMP MOTORS, R. W. Ager, AIEE TRANSACTIONS, volume 60, 1941, page 416.

the vertical plates receive a saw-tooth shaped voltage wave, which produces a linear horizontal sweep and allows visual observation of the shape of the complex wave. For wave analysis, the vertical plates are connected to a generator which will produce a nearly pure sine wave.

Since equation 2 is an expression representing a complex wave $f(\theta)$, let it represent the complex wave that is applied to the horizontal plates of the oscillograph. Also let $g(\theta) = -K \cos k(\theta + \alpha_k)$ be the sinusoidal wave applied to the vertical plates. The function $g(\theta)$ has a frequency k times the frequency of the fundamental of $f(\theta)$, so if k is an integer, a Lissajous figure will appear upon the oscillograph screen. The amplitude of $g(\theta)$ is K, and the angle α_k in the expression indicates the phase angle between $g(\theta)$ and the cosine term of the kth harmonic of $f(\theta)$.

Referring again to figure 1 and the discussion of plotting Lissajous figures, it is evident that the shape of the Lissajous figure depends upon the phase angle $k\alpha_k$. There is an infinite number of shapes that may be assumed as $k\alpha_k$ may assume an infinite number of values between 0 and 2π. If the frequency of $g(\theta)$ is not exactly a multiple of the frequency of $f(\theta)$, that is, if the two waves are not synchronized, the figure will gradually change through a complete cycle of shapes as the phase angle changes from 0 to 2π.

The area S_k of one of these figures may be calculated from the expressions of the two functions $f(\theta)$ and $g(\theta)$, and is as follows:

$$S_k = kK\pi(A_k \cos k\alpha_k + B_k \sin k\alpha_k) \qquad (3)$$

It will be noticed that this expression contains only two coefficients of the series

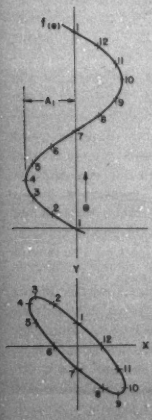
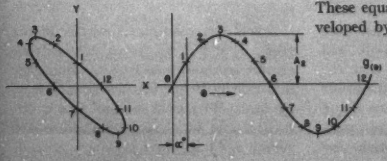


Figure 1. Plotting a simple Lissajous figure



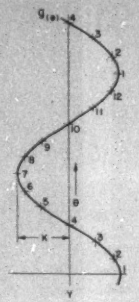
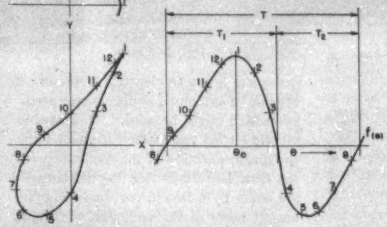


Figure 2. Plotting the Lissajous figure for the fundamental sine component of $f(\theta)$ with θ_0 at the positive peak



for $f(\theta)$. However, it is necessary to be able to solve for one of the coefficients independently. This may be done if another expression can be derived that will contain the same two coefficients. If the phase angle α_k were allowed to change to a new value, say β_k, the area of the figure would change to a new value S_k'. This area may be expressed similarly as

$$S_k' = kK\pi(A_k \cos k\beta_k + B_k \sin k\beta_k) \qquad (4)$$

If equations 3 and 4 are combined, the resulting expressions for A_k and B_k are as follows:

$$A_k = \frac{S_k \sin k\beta_k - S_k' \sin k\alpha_k}{kK\pi \sin k(\beta_k - \alpha_k)} \qquad (5)$$

$$B_k = \frac{S_k' \cos k\alpha_k - S_k \cos k\beta_k}{kK\pi \sin k(\beta_k - \alpha_k)} \qquad (6)$$

Complete derivations of the above equations are given in the appendices.

If the phase angles $k\alpha_k$ and $k\beta_k$ were made equal to 0 and $\frac{\pi}{2}$ respectively, equations 5 and 6 would reduce to

$$A_k = \frac{S_k}{kK\pi} \qquad (7)$$

$$B_k = \frac{S_k'}{kK\pi} \qquad (8)$$

These equations correspond to those developed by L. W. Chubb in connection with the Chubb polar analyzer.[4] However, the fact that it is difficult to accurately adjust the frequency and phase angle of the sine wave generator to a predetermined value precludes the use of the simple expressions in (7) and (8). An interesting analogy may be drawn at this point between this method and that of Chubb's. The vertical deflection of the unknown wave corresponds to Chubb's mechanical deflection by means of the templatc, and the oscillator corresponds to Chubb's simple harmonic motion. The cathode ray method is actually a simplification in apparatus of the Chubb method, making use of cathode ray tubes and oscillators to replace the Chubb mechanical apparatus. Like the Chubb method, this method will not apply to a determination of the constant term A_0 in a Fourier series. The constant term is relatively unimportant, and if it exists in a circuit, it may be determined by means of a direct current instrument.

It is interesting to note that the expressions 5 and 6 are both in terms of some area divided by π. The graphical method of analysis introduced by C. Runge[1] makes use of a theoretical area obtained by multiplying each ordinate by a function of the corresponding angle. The Lissajous figure automatically produces this same area as an actual figure that may be measured, with the exception that the area is multiplied by K the amplitude of $g(\theta)$, and k the order of the harmonic. Hence both K and k appear in the denominator of expressions 5 and 6.

Discussion of Experimental Procedures

In experimental analysis by means of the cathode ray method, several serious problems have been encountered; (1) the area of the Lissajous figure must be determined easily and accurately, (2) the sine wave source must be of a variable frequency and have very low harmonic content, (3) the frequency must be adjustable to synchronize with the fundamental of the complex wave, (4) the phase angle between the sine wave and the complex wave must be readily determined, and (5) results must be obtained in suitable units.

The Lissajous figure remains stationary on the screen only as long as the two waves are properly synchronized. With a little practice it may be possible to estimate the net area of a figure on the screen. A better practice, however, is to photograph the figure and later measure the area with an ordinary polar planimeter.

Figure 3 (left). Transformer exciting current wave

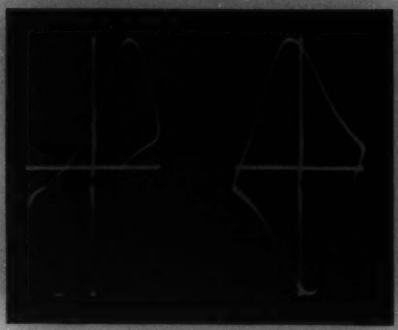


Figure 4 (right). A pair of Lissajous figures for determining the fundamental harmonic

The camera used is important, although an expensive one is not necessary. Better results will be obtained if the room is slightly darkened, but complete darkness is more of a handicap than a help. Since speed is more important than depth of focus, a fast lens is desirable. Also, the size of the image on the film demands that the camera be focused at distances in the vicinity of one or two feet. Once the camera is focused, however, it should not be changed during the process of analyzing a wave, as a change of focus would change the scale of units upon the film.

The sine wave source may be either a mechanical generator or an oscillator. The mechanical generator, of course, would be adaptable only at lower frequencies. In the 60 cycle range, the seventh harmonic is 420 cycles, and a generator producing from 60 to 420 cycles is a rare and expensive piece of equipment and may still develop a high percentage of harmonics. The most desirable characteristic of a mechanical generator would be the accuracy with which synchronism and phase relations could be worked out by mechanical gearing. In general a good quality variable frequency oscillator is more convenient to handle and more easily adjustable.

A number of different types of oscillators may be used. The only requirements are that the oscillator have a nearly constant amplitude over the proper frequency range and that the harmonic content be very small. The power required to maintain voltage across the plates of the tube is very small, so the power rating of the oscillator is relatively unimportant. However, if the output voltage is low, the oscillograph must have an amplifier to produce a figure of the desired size upon the screen.

The frequency of the oscillator must coincide exactly with that of the complex wave if a Lissajous figure is to remain stationary, and frequency drift of either the oscillator or the complex wave will cause the figure to change. There are a number of automatic synchronizing methods which might be used.[5] However, in all cases tried the method depends upon the interconnection of the oscillator with the complex wave, and the advantages are offset by a loss in the quality of the output wave of the oscillator. For this reason manual control of the frequency is desirable and a good frequency control is an important feature of the oscillator.

When the frequencies are synchronized so that the Lissajous figure remains stationary, there are a number of different shapes that the figure can assume. These depend upon the phase angle between the two waves. It is important to be able to determine this phase angle since it enters into the expression for the coefficients of the Fourier series, equations 5 and 6. In figure 2 a complex wave $f(\theta)$ has been plotted on the horizontal axis and a sine wave $g(\theta)$ has been plotted on the vertical axis. The Fourier series for $f(\theta)$ depends upon the location of a reference point where all the sine terms of the series are zero and all the cosine terms have a positive maximum value. Call this point θ_0. In many methods of analysis, the point where the complex wave crosses the axis is chosen for θ_0. For the cathode ray method of analysis, the maximum positive peak of $f(\theta)$ is thought to be a more suitable point for θ_0. The general expression for $g(\theta)$ in figure 2 is $g(\theta) = -K \cos k(\theta + \alpha_k)$. Since θ_0 is a value of θ such that $\sin(\theta_0) = 0$ and $\cos(\theta_0) = +1$, θ_0 is some multiple of 2π. Hence, $g(\theta)$ for $\theta = \theta_0$ reduces to

$$g(\theta_0) = -K \cos k\alpha_k \tag{9}$$

In figure 2, the Lissajous figure has been plotted for the case when $\alpha_k = 0$, and $g(\theta_0) = -K$. It will be noted that the Lissajous figure has a peak in the upper right corner a distance $-K$ from the Y axis. If α_k has a value other than zero, $g(\theta_0)$ will be reduced in magnitude and the peak will have moved a distance $(K - K \cos k\alpha_k)$ to the left. The peak can always be located on the oscillogram and $g(\theta_0)$ may be measured directly. Then the angle $k\alpha_k$ is, from equation 11,

$$k\alpha_k = \cos^{-1}(g(\theta_0)/K) \tag{10}$$

From equation 10, $k\alpha_k$ may be either positive or negative since the cosine is the same for either case, but in writing the sine of $k\alpha_k$, it is important to know whether $k\alpha_k$ is positive or negative. It is positive if $g(\theta)$ has already passed its negative maximum at the time $f(\theta)$ reaches its peak value. The best way to determine this when viewing the figure on the oscillograph screen is to adjust the frequency of the sine wave generator to a value slightly greater than that of the harmonic and stop the figure by synchronizing the two frequencies after the peak has left the upper right corner moving to the left. If the peak is stopped before it reaches the midpoint, the angle will be between 0° and 90°, while if it is stopped between the midpoint and the upper left corner, the angle will be between 90° and 180°. It is good practice to make $k\alpha_k$ about 45° and $k\beta_k$ about 135°.

It is important in planimetering the area of the Lissajous figures, to move always in the proper direction around the loops, for some areas may be positive and some negative. A simple way to do this is always to start from the peak point on the Lissajous figure and move downward to the left, thus tracing through one complete cycle. The reading on the planimeter is or can be corrected to square inches.

Now if the scales for all figures are the same, A_k and B_k can be calculated from equations 5 and 6 in inches. However, it is usually better to convert each area by means of its scale constant to a hypothetical unit, which may be called square volts if a voltage wave is being analyzed,

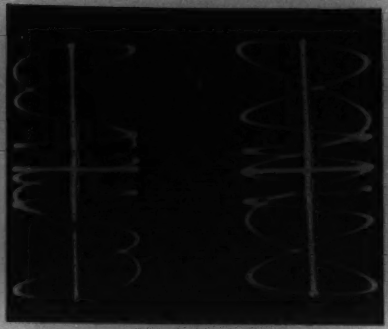


Figure 5. A pair of Lissajous figures for determining the seventh harmonic

Figure 6. Calibration picture

or square amperes for a current wave. Then K (assumed constant) can be converted to the correct units, and the value of A_k is derived in those units. If K is not constant, equations 5 and 6 must be altered as follows:

$$A_k = \frac{S_k/K \sin k\beta_k - S_k'/K' \sin k\alpha_k}{kr \sin k(\beta_k - \alpha_k)} \qquad (11)$$

$$B_k = \frac{S_k'/K' \sin k\alpha_k - S_k/K \cos k\beta_k}{kr \sin k(\beta_k - \alpha_k)} \qquad (12)$$

The scale constant may be determined by taking a picture of a pure sine wave of known amplitude at the same time the other pictures are being taken. In fact, it is a good practice to take two or three calibration pictures during an experiment. Obviously, a change in amplification on the oscillograph or focus of the camera will alter the scale constant. If the scale constant varies slightly for unavoidable reasons, either an average constant must be used or individual constants must be assigned to each picture.

Experimental Results

In order to determine to some extent how practical the cathode ray method of wave analysis is, an exciting current wave for a potential transformer was analyzed. Figure 3 shows an oscillogram of the wave that was analyzed. The results of the cathode ray method were compared with results using another method of analysis. The other method was the graphical method of C. Runge using 72 points.[3] A comparison of results is shown in table I. The analysis was only carried as far as the seventh harmonic as the graphical method becomes very inaccurate for higher harmonics and correspondingly small magnitudes. It is thought that the two methods possess about the same degree of accuracy for low order harmonics up to the third, but for higher harmonics the cathode ray method is thought to be more accurate. The areas of the Lissajous figures for higher harmonics may be rather accurately determined because they are proportional to the order of the harmonic k times the magnitude of the corresponding coefficients.

Figures 4 and 5 show examples of some of the Lissajous figures that were used in the experimental analysis. The pictures were taken using a 35 mm. camera with an f-4.5 lens. Exposures were made at $^1/_{25}$ of a second. This was found to give a very good trace on the film when the intensity of the cathode ray was adjusted to a reasonable brightness. Since the light emitted from a cathode ray oscillograph screen is very small, a camera with a fast lens is a distinct advantage. Another desirable feature in this application is a short focus, since the size of the figures on the screen is hardly more than two inches high. The zero axes of the Lissajous figures were obtained by exposing the film once with the exciting current wave shorted out and once with the sine wave shorted out in addition to the exposure for the figure itself. Figure 6 is an example of one of the calibration pictures that were taken. It is a Lissajous figure similar to those in figure 4 except that both waves are sinusoidal.

Figure 7 shows the equipment as it was assembled for the experimental analysis. The cathode ray oscillograph had a 5 inch screen and the size of the figure could be adjusted through step up amplifiers on both the horizontal and vertical plates. The oscillator was a beat frequency type having a frequency range from 20 to 17,000 cycles and a practically constant amplitude over that range. Just in front of the oscillator and to the left is a small tuning condenser which was used in parallel with the main tuning condenser on the oscillator to give a finer adjustment of frequency.

Conclusion

It is important to note that only standard laboratory equipment is necessary for the cathode ray analysis. The method is much faster and less tedious than the graphical method, because most of the calculation is dispensed with. Harmonics that do not exist, or are negligible, are apparent at once from the areas of the Lissajous figures without further calcu-

Table I. Comparison of Results in an Experimental Analysis of a Transformer Exciting Current

	Cathode-Ray Method		Runge Method	
Harmonic	Magnitude Amperes	Phase Angle Degrees	Magnitude Amperes	Phase Angle Degrees
First	0.318	0	0.327	0
Third	0.1120	44.2	0.1135	50.0
Fifth	0.0267	54.5	0.0248	59.0
Seventh	0.00794	7.7	0.00735	12.6

Figure 7. Apparatus used for the experimental analysis

lation. The other harmonics may be quickly calculated and converted to the correct units.

But much more important than any other advantage is the fact that the cathode ray oscillograph will respond effectively to much higher frequencies than any other type of oscillograph. The vibrator elements in most mechanical oscillographs have a natural frequency of 5,000 cycles per second undamped; so it is evident that any frequency in this range would be somewhat magnified and the results would be erratic. The cathode ray oscillograph may be used in the radio frequency range. Thus, high frequency waves may be analyzed with the same simplicity and completeness as are the power frequency waves.

With the possibility of completely analyzing higher frequency waves, the study of mechanical vibration may be accelerated and improved. A device that would couple the mechanical system to an electrical circuit and reproduce the mechanical oscillations as electrical functions would make possible the analysis of mechanical vibration with a cathode ray oscillograph.

The frequency range of cathode ray oscillographs has been still further increased with the invention of a new microwave oscillograph devised for the centimeter range of wave lengths, where ordinary oscillographs are not adaptable.[8] These high frequency waves are distorted in the ordinary cathode ray oscillograph because the finite time required for an electron to pass across a deflecting field is of the same order of magnitude as the time required for one cycle of the wave. Also, if the two deflection fields are spaced along the direction of the beam, the time lag between the two fields is an appreciable part of a cycle. In the microwave oscillograph, the deflection fields are made small and brought very close together. All dimensions of the tube are likewise reduced, and the image is thrown upon an especially fine grain fluorescent screen. The image itself is so small that it must be observed and photographed by means of a microscope. This new instrument should make ultra-high frequency wave analysis possible, with very little change from the method described in this paper.

Appendix I

Areas of Lissajous Figures

The general expression for the sinusoidal function is

$$g(\theta) = -K \cos k(\theta + \alpha_k) \tag{13}$$

and

$$\begin{aligned} dg(\theta) &= kK \sin k(\theta + \alpha_k)d\theta \\ &= kK(\cos k\alpha_k \sin k\theta + \sin k\alpha_k \cos k\theta)d\theta \end{aligned} \tag{14}$$

The area of the Lissajous figure is

$$S_k = \int_0^{2\pi} f(\theta)dg(\theta) \tag{15}$$

The complex function $f(\theta)$, given in equation 2, may be changed to the following form:

$$f(\theta) = A_0 + \sum_{n=1}^{\infty} A_n \sin n\theta + \sum_{n=1}^{\infty} B_n \cos n\theta \tag{16}$$

The integration may be carried out for each part of $f(\theta)$ independently as follows:

$$\int_0^{2\pi} A_k kK \sin k(\theta + \alpha_k)d\theta = 0$$

$$\int_0^{2\pi} (A_n \sin n\theta)(kK \cos k\alpha_k \sin k\theta)d\theta = 0 \quad \text{if } n \neq k$$

$$\int_0^{2\pi} (A_n \sin n\theta)(kK \sin k\alpha_k \cos k\theta)d\theta = 0 \quad \text{for all } n$$

$$\int_0^{2\pi} (B_n \cos n\theta)(kK \cos k\alpha_k \sin k\theta)d\theta = 0 \quad \text{for all } n$$

and

$$\int_0^{2\pi} (B_n \cos n\theta)(kK \sin k\alpha_k \cos k\theta)d\theta = 0 \quad \text{if } n \neq k$$

If $n = k$

$$\int_0^{2\pi} (A_n \sin n\theta)(kK \cos k\alpha_k \sin k\theta)d\theta = A_k kK \cos k\alpha_k \int_0^{2\pi} \sin^2 k\theta d\theta = (A_k kK \cos k\alpha_k)\pi$$

and

$$\int_0^{2\pi} (B_n \cos n\theta)(kK \sin k\alpha_k \cos k\theta)d\theta = B_k kK \sin k\alpha_k \int_0^{2\pi} \cos^2 k\theta d\theta = (B_k kK \sin k\alpha_k)\pi$$

Only two terms remain in the expression for the area S_k.

$$\begin{aligned} S_k &= A_k kK\pi \cos k\alpha_k + B_k kK\pi \sin k\alpha_k \\ &= kK\pi(A_k \cos k\alpha_k + B_k \sin k\alpha_k) \end{aligned} \tag{17}$$

Since it is known that α_k may assume a new value β_k, the expression for S_k' may be written immediately,

$$S_k' = kK\pi(A_k \cos k\beta_k + B_k \sin k\beta_k) \tag{18}$$

Appendix II

Derivation of General Expression for the Coefficients

Equations 17 and 18 may be changed to the following form:

$$A_k \cos k\alpha_k + B_k \sin k\alpha_k = \frac{S_k}{kK\pi} \tag{19}$$

$$A_k \cos k\beta_k + B_k \sin k\beta_k = \frac{S_k'}{kK\pi} \tag{20}$$

These equations may be solved by determinants for the coefficients A_k and B_k.

$$A_k = \frac{\frac{1}{kK\pi}\begin{vmatrix} S_k, \sin k\alpha_k \\ S_k', \sin k\beta_k \end{vmatrix}}{\begin{vmatrix} \cos k\alpha_k, \sin k\alpha_k \\ \cos k\beta_k, \sin k\beta_k \end{vmatrix}} = \frac{\frac{1}{kK\pi}(S_k \sin k\beta_k - S_k' \sin k\alpha_k)}{\cos k\alpha_k \sin k\beta_k - \cos k\beta_k \sin k\alpha_k}$$

$$= \frac{S_k \sin k\beta_k - S_k' \sin k\alpha_k}{kK\pi \sin k(\beta_k - \alpha_k)}$$

$$B_k = \frac{\frac{1}{kK\pi}\begin{vmatrix} \cos k\alpha_k, S_k \\ \cos k\beta_k, S_k' \end{vmatrix}}{\begin{vmatrix} \cos k\alpha_k, \sin k\alpha_k \\ \cos k\beta_k, \sin k\beta_k \end{vmatrix}} = \frac{\frac{1}{kK\pi}(S_k' \cos k\alpha_k - S_k \cos k\beta_k)}{\cos k\alpha_k \sin k\beta_k - \cos k\beta_k \sin k\alpha_k}$$

$$= \frac{S_k' \cos k\alpha_k - S_k \cos k\beta_k}{kK\pi \sin k(\beta_k - \alpha_k)}$$

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The Apparent-Impedance Method of Calculating Single-Phase-Motor Performance

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Synopsis: In the past several years there have been offered a number of calculation methods to be used in connection with predetermining the performance of single-phase induction motors. While such methods are usually based upon either the cross field or the revolving field theory, they differ from each other according to individual preferences.

In the present paper there is proposed a method which seems to be convenient and simple, and which, because of symmetry, involves a minimum of charts in carrying out the necessary calculations. The method is proposed because it has been used in one design department for a number of years and found to be very satisfactory as a practical method.

IN the calculation of performance of single-phase motors by the revolving-field theory, there appear repeatedly certain quantities which have been defined as apparent impedances. The actual determination of an apparent impedance when the characteristic impedances of the motor are known involves a considerable amount of labor and the use of complex quantities. This labor has caused some engineers to avoid a straightforward use of the revolving-field theory and to substitute artificial steps, or actually to use entirely different methods. In a case such as this it is often convenient to consider whether the labor of calculation could be avoided by the use of a suitable chart wherein the calculational work is done once and for all and, for a specific calculation, it is merely necessary to read the values from the chart. It is the principal purpose of this paper to indicate how such charts may be constructed for the determination of apparent impedance and to show how the use of such charts can be made to simplify induction-motor performance calculations.

Per-Unit Apparent-Impedance Charts

The values of the apparent impedances of a single-phase motor were given in equations 54 to 57, inclusive, of my 1929 paper[1] on the revolving-field theory. These values are indicated below in equations 1 to 4.

$$R_f = \frac{X_m^2 \frac{R_2}{s}}{\left(\frac{R_2}{s}\right)^2 + (X_2 + X_m)^2} \tag{1}$$

$$X_f = \frac{X_m\left[\left(\frac{R_2}{s}\right)^2 + X_2(X_2 + X_m)\right]}{\left(\frac{R_2}{s}\right)^2 + (X_2 + X_m)^2} \tag{2}$$

$$R_b = \frac{X_m^2\left(\frac{R_2}{2-s}\right)}{\left(\frac{R_2}{2-s}\right)^2 + (X_2 + X_m)^2} \tag{3}$$

$$X_b = \frac{X_m\left[\left(\frac{R_2}{2-s}\right)^2 + X_2(X_2 + X_m)\right]}{\left(\frac{R_2}{2-s}\right)^2 + (X_2 + X_m)^2} \tag{4}$$

The right-hand members of each of the above four equations contain three independent variables, if R_2/s and $R_2/(2-s)$ be each considered as a single variable. Functions involving three independent variables are usually considered too complicated to chart since they involve families of curves. However, if the apparent impedances and each of the independent variables of the preceding equations be expressed as per unit of one of the independent variables, it is possible to reduce the number of independent variables by one. This can be done if both sides of the four above equations be divided by X_m and both the numerator and denominator of each of the right-hand members be divided by X_m^2. The resulting equations are given in 5 to 8 below:

$$\frac{R_f}{X_m} = \frac{\frac{R_2}{X_m s}}{\left(\frac{R_2}{X_m s}\right)^2 + \left(\frac{X_2}{X_m} + 1\right)^2} = \text{per unit forward field apparent resistance} \tag{5}$$

$$\frac{X_f}{X_m} = \frac{\left(\frac{R_2}{X_m s}\right)^2 + \frac{X_2}{X_m}\left(\frac{X_2}{X_m} + 1\right)}{\left(\frac{R_2}{X_m s}\right)^2 + \left(\frac{X_2}{X_m} + 1\right)^2} = \text{per unit forward field apparent reactance} \tag{6}$$

$$\frac{R_b}{X_m} = \frac{\frac{R_2}{X_m(2-s)}}{\left(\frac{R_2}{X_m(2-s)}\right)^2 + \left(\frac{X_2}{X_m} + 1\right)^2} = \text{per unit backward-field apparent resistance} \tag{7}$$

$$\frac{X_b}{X_m} = \frac{\left(\frac{R_2}{X_m(2-s)}\right)^2 + \frac{X_2}{X_m}\left(\frac{X_2}{X_m} + 1\right)}{\left(\frac{R_2}{X_m(2-s)}\right)^2 + \left(\frac{X_2}{X_m} + 1\right)^2} = \text{per unit backward-field apparent reactance} \tag{8}$$

In equations 5 to 8 the independent variables will have the following definitions:

$\frac{R_2}{X_m s}$ = per unit secondary resistance at slip s

$\frac{R_2}{X_m(2-s)}$ = per unit secondary resistance at slip $2-s$

$\frac{X_2}{X_m}$ = per unit secondary reactance

On the basis of the above definitions of the independent variables, there are only two independent variables in the right-hand members of equations 5 to 8. It therefore becomes possible to plot each of equations 5 to 8 in the form of a family of curves. Since the only difference between the expressions for per unit apparent forward field resistance and reactance and the similar expressions for the backward field is the use of R_2/s in place of $R_2/(2-s)$, the curves for the forward and backward field apparent impedances will be identical and only two families of curves need be drawn.

In figures 1 and 2 there are shown curves of per unit apparent resistance and per unit apparent reactance plotted for definite values of per unit secondary reactance and as a function of the reciprocal of the per unit secondary resistance for slips of s or $2-s$. The reciprocal of the per unit secondary resistance has been chosen as the independent variable because the resulting curves spread out in such a fashion as to make them more easily and more accurately read.

In order to make use of the charts and to obtain an actual value of apparent resistance or reactance, it is first necessary to obtain the per unit secondary reactance, X_2/X_m, to learn which of the curves

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1. For all numbered references, see list at end of paper.

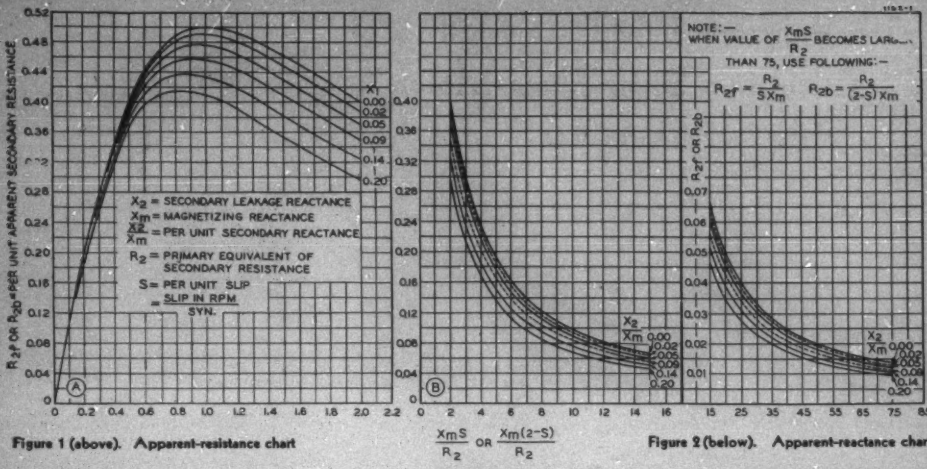
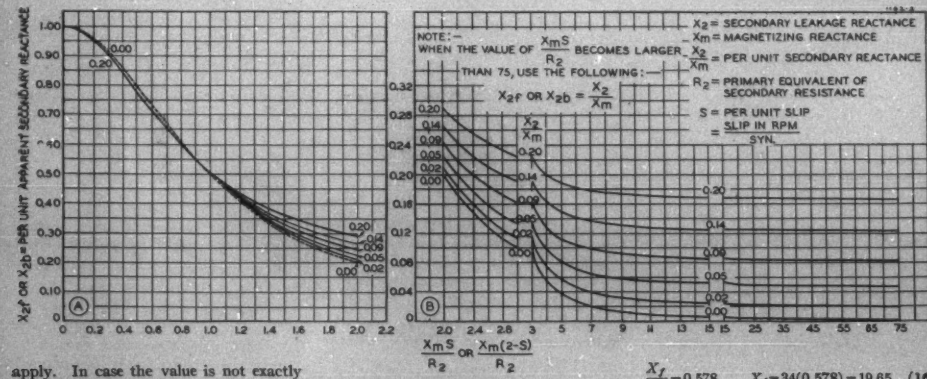

R_{2f} OR R_{2b} = PER UNIT APPARENT SECONDARY RESISTANCE
X_2 = SECONDARY LEAKAGE REACTANCE
X_m = MAGNETIZING REACTANCE
$\frac{X_2}{X_m}$ = PER UNIT SECONDARY REACTANCE
R_2 = PRIMARY EQUIVALENT OF SECONDARY RESISTANCE
S = PER UNIT SLIP = SLIP IN RPM / SYN.
$\frac{X_2}{X_m}$ 0.00 0.02 0.05 0.09 0.14 0.20
A
B
$\frac{X_m S}{R_2}$ OR $\frac{X_m(2-S)}{R_2}$
NOTE:— WHEN VALUE OF $\frac{X_m S}{R_2}$ BECOMES LARGER THAN 75, USE FOLLOWING:—
$R_{2f} = \frac{R_2}{S X_m}$ $R_{2b} = \frac{R_2}{(2-S) X_m}$
R_{2f} OR R_{2b}

Figure 1 (above). Apparent-resistance chart

Figure 2 (below). Apparent-reactance chart


X_{2f} OR X_{2b} = PER UNIT APPARENT SECONDARY REACTANCE
X_2 = SECONDARY LEAKAGE REACTANCE
X_m = MAGNETIZING REACTANCE
$\frac{X_2}{X_m}$ = PER UNIT SECONDARY REACTANCE
R_2 = PRIMARY EQUIVALENT OF SECONDARY RESISTANCE
S = PER UNIT SLIP = SLIP IN RPM / SYN.
$\frac{X_2}{X_m}$ 0.00 0.02 0.05 0.09 0.14 0.20
A
B
$\frac{X_m S}{R_2}$ OR $\frac{X_m(2-S)}{R_2}$
NOTE:— WHEN THE VALUE OF $\frac{X_m S}{R_2}$ BECOMES LARGER THAN 75, USE THE FOLLOWING:—
X_{2f} OR $X_{2b} = \frac{X_2}{X_m}$

apply. In case the value is not exactly the same as that of a curve, it is, of course, necessary to interpolate between two adjacent curves.

Once the proper curve has been selected, the corresponding value of per unit apparent resistance or reactance may be read as the ordinate corresponding to the proper value of $X_m s/R_2$ or $X_m(2-s) \div R_2$. The actual apparent resistance or reactance is obtained as the product of the per unit apparent resistance or reactance by X_m, the magnetizing reactance.

As an example of actual use of these curves, consider the case of a single-phase motor having the following constants:

$$R_1 = 2 \tag{9}$$

$$X_1 = 1.7 \tag{10}$$

$$X_m = 34 \tag{11}$$

If this motor is operating at a slip of 0.05, the per unit forward and backward field secondary reactances will be

$$\frac{X_1}{X_m} = \frac{1.7}{34} = 0.05 \tag{12}$$

and the reciprocal of the per unit forward and backward field secondary resistances will be

$$\frac{X_m^2}{R_1} = \frac{34(0.05)}{2} = 0.85 \tag{13}$$

$$\frac{X_m(2-s)}{R_1} = \frac{34(1.95)}{2} = 33.2 \tag{14}$$

Using these values and figures 1 and 2, the per unit apparent impedances and the corresponding actual impedance values are given below:

$$\frac{R_f}{X_m} = 0.475 \qquad R_f = 34(0.475) = 16.18 \tag{15}$$

$$\frac{X_f}{X_m} = 0.578 \qquad X_f = 34(0.578) = 19.65 \tag{16}$$

$$\frac{R_b}{X_m} = 0.0273 \qquad R_b = 34(0.0273) = 0.928 \tag{17}$$

$$\frac{X_b}{X_m} = 0.0482 \qquad X_b = 34(0.0482) = 1.638 \tag{18}$$

Calculation of Single-Phase-Motor Performance

In the calculation of motor performance it is usually desirable to proceed from a relatively simple idealized conception and to introduce phenomena of secondary importance by modifying the results obtained from the idealized concept. For example: The equivalent circuit for the single-phase motor which was given in figure 1 of my 1929 paper (figure 3 of the present paper), and which has appeared many times in publications by other authors, makes no provision for repre-

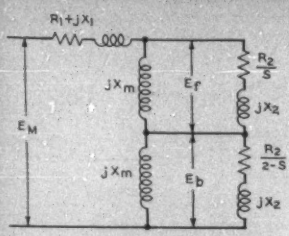


Figure 3. Single-phase-motor equivalent circuit

PERFORMANCE CALCULATING SHEET
SINGLE PHASE MOTORS

MOTOR CONSTANTS

$R_1 = 2$ $X_1 = 2.8$ $X_m = 34$ $W_c = 13$
$R_2 = 2$ $X_2 = 1.7$ $W_f = 20$

PERFORMANCE WHEN S=.05
RPM = (1-S)(SYN)
= (.95)(1800) = 1710

(1) $\frac{X_2}{X_m} = \frac{(1.7)}{(34)} = .05$

(2) $\frac{X_m S}{R_2} = \frac{(34)(.05)}{(2)} = .85$

(3) $\overset{\text{Per unit}}{R_{2f}} = (.475)$ (4) $\overset{\text{Per unit}}{X_{2f}} = (.578)$

(5) $\frac{X_m(2-S)}{R_2} = \frac{(34)(1.95)}{(2)} = 33.2$

(6) $\overset{\text{Per unit}}{R_{2b}} = (.0273)$ (7) $\overset{\text{Per unit}}{X_{2b}} = (.0482)$

(8) $R = (\overset{\text{Per unit}}{R_{2f}} + \overset{\text{Per unit}}{R_{2b}})X_m + R_1 = [(.475)+(.0273)](34)+(2) = 19.11$

(9) $X = (\overset{\text{Per unit}}{X_{2f}} + \overset{\text{Per unit}}{X_{2b}})X_m + X_1 = [(.578)+(.0482)](34)+(2.8) = 24.09$

(10) $\frac{R}{X} = \frac{(19.11)}{(24.09)} = .793$

(11) $\cos\phi = .621$

(12) $I = \frac{E\cos\phi}{R} = \frac{(110)(.621)}{(19.11)} = 3.57$

(13) W.O. $= \left\{\left[R_{2f} - R_{2b}\right]X_m I^2\right\}(1-S) - W_f$
$= \left\{\left[(.475)-(.0273)\right](34)(12.75)\right\}(.95) - (20) = 164$

(14) W.I. $= EI\cos\phi + W_c$
$= (110)(3.57)(.621) + (13) = 257$

(15) Eff. $= \frac{\text{W.O.}}{\text{W.I.}} = \frac{(164)}{(257)} = .638$

(16) RPM $= (1-S)(SYN) = (.95)(1800) = 1710$

Figure 4. Single-phase-motor calculation sheet

senting the core-loss current. Such current could be shown as flowing through a high resistance which is connected in parallel with the magnetizing reactance of each forward and backward field. In actual practice it is usually found that the effect of the core-loss current on the motor performance is relatively small since the current itself is usually very small and since its time-phase relation is at 90 degrees with respect to the magnetizing current, which latter is usually relatively large. For this reason, it has usually been found desirable to consider the core loss as if it were the result of a high resistance in parallel with the entire motor and to neglect the effect of the flow of the core-loss current through the primary impedance of the motor. When this approach is employed, the core loss may be introduced as an input which is added to the input determined from the idealized equivalent circuit.

There are two other losses which must be accounted for in making an exact single-phase motor calculation and these are the rotational iron loss and the mechanical friction, sometimes called friction and windage. The rotational iron loss is indistinguishable from friction in its effect upon motor performance since the loss appears as a retarding torque tending mechanically to slow down the motor. The torque of rotational core loss differs from the torque of friction in that, in addition to being a function of speed, it is also a function of the currents in the stator and the rotor and, while an exact expression for the torque would be complicated, it and the corresponding power loss may be approximately represented as proportional to the second power of the stator current.

If it be presumed that the rotational iron loss and the mechanical friction are both known, and that the two rotational losses be classed as friction and represented by the symbol W_f, the effect of this combined rotational loss is properly accounted for if W_f be subtracted from the electrical output as determined from the idealized circuit.

On the basis of these remarks, the calculation sheet for a single-phase motor may be laid out as shown in figure 4 in which an actual calculation has been carried out using the constants which were employed in explaining the apparent-impedance charts, plus the values for the primary resistance and reactance, the iron loss, and the rotational losses as given below:

$R_1 = 2$ (19)

$X_1 = 2.8$ (20)

$W_c = 13$ (21)

$W_f = 20$ (22)

In carrying out the operation of determining the input current, it has been thought desirable to make use of figure 5

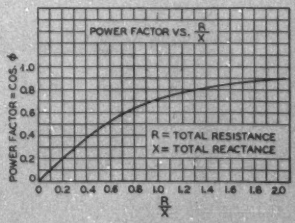


Figure 5. Power-factor versus R/X chart

and the total apparent secondary resistance, thus avoiding the necessity of squaring the impedances and extracting the square root or carrying certain quantities in mind during the calculation, as is necessary with other methods.

It will be seen from the calculation form that the number of steps required for the determination of the performance of a single-phase motor for any given

PERFORMANCE CALCULATING SHEET
CAPACITOR MOTORS

8a

R_m = _____ X_m = _____ $\frac{X_m S}{R_2}$ = _____ R_{2f} = _____

R_2 = _____ X_2 = _____ R_{2b} = _____

R_1 = _____ X_1 = _____ $\frac{X_m(2-S)}{R_2}$ = _____ SUM _____ DIF. _____

R_c = _____ X_c = _____ X_{2f} = _____

W_f = _____ W_r = _____ $X_c - X_1$ = _____ X_{2b} = _____

a = _____ X_m = _____ X_2/X_m = _____ SUM _____ DIF. _____

(1) $\frac{X_m(R_{2f}+R_{2b})}{(\quad)(\quad)}$ = (2) $\frac{X_m(X_{2f}+X_{2b})}{(\quad)(\quad)}$ =

(3) $\frac{X_m(R_{2f}-R_{2b})}{(\quad)(\quad)}$ = (4) $\frac{X_m(X_{2f}-X_{2b})}{(\quad)(\quad)}$ =

(5) $(R_1 + (1))$ = (6) $(X_1 + (2))$ =

(7) $(R_c + a^2(1))$ = (8) $(X_c + a^2(2))$ =

(9) $\frac{a\,(3)}{(\quad)(\quad)}$ = (10) $\frac{a\,(4)}{(\quad)(\quad)}$ =

(11) $(9)^2 - (10)^2$ = (12) $2(9)(10)$ =

(13) $(9)(7) - (6)(8)$ = (14) $(5)(8) + (6)(7)$ =

(15) $(13) - (11)$ = (16) $(14) - (12)$ =

(17) $(15)^2 + (16)^2$ =

(18) $\frac{E(15)}{(17)} = \frac{(\quad)(\quad)}{(\quad)}$ = (19) $\frac{E(16)}{(17)} = \frac{(\quad)(\quad)}{(\quad)}$ =

(20) $(7) - (10)$ = (21) $(8) + (9)$ =

(22) $(5) + (10)$ = (23) $(6) - (9)$ =

(24) $(18)(20) + (19)(21)$ = (25) $(18)(21) - (19)(20)$ =

(26) $(16)(22) + (19)(23)$ = (27) $(18)(23) - (19)(22)$ =

(CONTINUED ON PAGE 2)

Pg. 1

PERFORMANCE CALCULATING SHEET
CAPACITOR MOTORS

8a

(28) $(24) + (26) = (\quad) + (\quad) =$ (29) $(25) + (27) = (\quad) + (\quad) =$

(30) $\frac{R}{X} = \frac{(\quad)}{(\quad)} =$ (31) $\cos\phi =$

(32) $\frac{(24)^2 + (25)^2 + [(26)^2 + (27)^2](a^2)}{(\quad) + (\quad) + [\quad)+(\quad)](\quad)} =$

(33) $(24)(27) - (25)(26) =$

(34) $\frac{(32)}{(\quad)(\quad)} =$ (35) $2(a)(33)(1) =$

(36) $W.O. = \frac{[(34)+(35)](1-S) - W_f}{[\quad)+(\quad)](\quad) - (\quad)} =$

(37) $W.I. = \frac{(28)(E)}{(\quad)(\quad)} + (W_r) =$

(38) $Eff. = \frac{(36)}{(37)} = \frac{(\quad)}{(\quad)} =$ (39) $I = \frac{(28)}{(31)} = \frac{(\quad)}{(\quad)} =$

(40) $T = \frac{(36)}{(1-S)}\left[\frac{112.7}{SYN}\right] = \frac{(\quad)}{(\quad)}(\quad) =$

(41) $(24)^2 + (27)^2$ = (42) $RPM = (1-S)(SYN)$ =

(43) $KVA = \frac{(41)(X_c - X_1)}{(\quad)(\quad)} =$ (44) $E_c = \sqrt{(41)}(X_c - X_1) =$

Pg. 2

Figure 6. Capacitor-motor calculation sheet

A Novel Reclosing Relay

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MEMBER AIEE

Synopsis: This paper describes a reclosing relay for oil circuit-breaker control which is new in design, new in function, and new in operation. It was designed and built with additional features to meet certain reclosing requirements which cannot be obtained by use of standard reclosing relays. These reclosing requirements, brought about by complete automatization of high-voltage oil circuit-breakers in transmission networks and on lines containing automatic sectionalizing air-break switches, are herein described. Also several schemes of time-sequence-coordination are given for the operation of oil circuit-breakers with automatic line sectionalizing air-break switches. Of special interest is a scheme for materially reducing fuse outages, which utilizes the described reclosing relay for coordinating the operations of a breaker with fuse operations on the line served by the breaker.

BECAUSE of the greater exposure and higher potential stresses of the transmission system over those of the generation and distribution systems, most interruptions to electric service are caused by failures in the transmission process. Although transmission lines can be built almost interruption proof by utilizing modern design, the fact remains that the greater number of lines were built several years past when such quality lines, if at all possible, were so only at a prohibitive cost. Thus the major problem is simply an economical balance between what can be done to reduce the number of interruptions and what can be done to minimize or remove the adverse effects of those which do occur. It is a question whether to rebuild the older lines or accept the interruptions as inevitable and minimize their adverse effects upon service.

It is not the author's purpose to answer this question since each power company must work out its own problems. The author does wish, however, to discuss that side of the question regarding means for minimizing the adverse effects of service interruptions due to faults on the transmission system.

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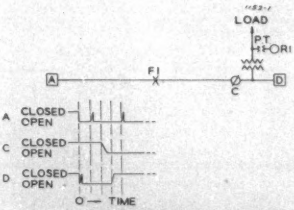

Figure 1. Operation-sequence diagram of line breakers and one automatic sectionalizing air-break switch with low side potential control for opening only

Service interruptions seldom result from failure of the conductor, but are caused by short circuits resulting from lightning. Accompanying voltage disturbances, however, can be practically nullified by the use of high speed relays, a fact which is repeatedly demonstrated on the Oklahoma Gas & Electric Company system. Large industrial motor loads now ride through all disturbances, whereas before installation of such relays these loads were occasionally lost. Moreover, since installing them permanent faults are a rarity and insulator replacements are few because the power is interrupted before burning action effects permanent damage.

Breaker-Reclosing Equipment, Transmission System

Although fast clearing of faults minimizes the voltage disturbance to remaining parts of system and greatly reduces the possibility of permanent line damage, it still interrupts service to consumers served from or through the faulted section. Through the modern practice of equipping breakers with automatic reclosing relays, the duration of such an interruption is greatly minimized. But when the breaker is located within a transmission network, its reclosing requirements necessitate the use of a reclosing relay having greater utility than the standard makes now available. The latter relays are generally designed for use on distribution feeders or radial transmission lines where the only requirements are to perform upon a breaker a certain number of closures at definite time intervals, and to lock out the breaker from further closures if the final closure is unsuccessful because of a permanent fault.

value of slip is very small. The time required for a single calculation should not exceed five to ten minutes and, where a number of calculations are done in parallel, even this time can usually be bettered.

Apparent impedance charts are not confined to the calculation of single-phase motors, but they may also be applied to polyphase motors, shaded pole motors, shading coils of relays, and other electrical devices. A calculation form for polyphase motors is too obvious and simple to present here, but in a similar way to that which has been used for the straight single-phase motor, it is possible to lay out a calculation form for an unbalanced two-phase motor such as the capacitor motor. An example of a calculation form of this type is shown in figure 6.

Advantages

The advantage of the apparent impedance method as herein outlined for the calculation of induction motor performance lies in the symmetry and naturalness of the approach. This symmetry is particularly indicated by the fact that the curves for the forward and backward field impedances are identical and the further fact that these impedances may not only be used in a simple fashion to obtain the input current, but the same quantities are also used in equally simple fashion in expressions for torque and output.

It is felt that the use of the apparent impedance charts not only eliminates considerable labor, but also a great deal of the possibility of error, for with the use of the charts, the calculational operations are reduced to arithmetic and complex quantities need not be considered.

A further advantage of the method lies in the assistance which it gives to a visualization of how the motor characteristics vary as the constants are changed. The separate points of a calculation are tied together mentally through the continuity of the curves.

In the determination of motor constants from test, the apparent impedance charts are used in reverse because apparent impedances at definite speeds are known and it is desired to find the true impedances.

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Such relays cannot be used in transmission networks because they are either unidirectional in operation, which requires extended resetting times, or they cannot be adapted to the conditions desired without use of extra equipment.

Need for a Reclosing Relay for Functioning Under Variable Line Conditions

A reclosing relay for transmission network use must be capable of distinguishing between energized and de-energized line conditions. Also, it must be adaptable for use in conjunction with synchronism-check relays for closing breakers on in-phase conditions. For example, it may be desirable to limit to one terminal the re-energization of a transmission line following tripouts, with closure of the remaining terminal breaker permitted only after successful re-energization of the line. The first requires closures on "de-energized line" only, and the second requires closures on "energized line" only which may also require synchronism-check.

For use in unattended and semi-attended substations a reclosing relay must be capable of one or more subsequent reclosures in addition to the immediate or delayed initial reclosure, since operating experience shows that out of the total tripouts about 85% are successfully re-energized by an immediate breaker reclosure, 10% by a second reclosure, 1% by a third reclosure, and 4% result in permanent faults. The percentage of successful immediate reclosures on circuits equipped with modern high speed fault clearing relays is above average and the percentage of permanent faults is far below average.

Need for a Fast Accurate-Timing Reclosing Relay

Transmission lines are customarily divided into several parts by airbreak switches so that any one section, on becoming faulty, can be removed and service restored to the remaining parts. Most airbreak switches are, as yet, manually operated but with service requirements becoming more exacting, automatization of certain airbreak switches affords an inexpensive means of speeding service restoration to loads tapped on transmission lines.

Airbreak switches are generally incapable of interrupting fault currents. They are designed to be opened under normal service conditions. Therefore, under fault conditions they must be opened after the line is de-energized and the time of opening must be coordinated with the time of re-energization of the circuit by the terminal breakers of the line. To accomplish this time coordination between the automatic sectionalizing switches and line breakers and yet restore service in minimum time, requires the use of a fast accurate breaker-control relay. Short time intervals between breaker reclosures are essential in order to minimize the time gaps between operations of the breakers and sectionalizing switches.

The extent to which an airbreak switch need be automatized depends upon service requirements of the load or loads protected and the quality of the transmission line serving the loads. Several schemes of time-sequence-coordination are given below as examples, in which the operations of airbreak switches are controlled from potential indications only.

Figure 1 shows a single airbreak switch *C* automatized for opening only. No high tension potential device is required for airbreak switch control, the potential indication to control relay *R*1 being received from low side of power transformer as indicated. This scheme is applicable for protecting a load tapped between a long and a short section of line where few

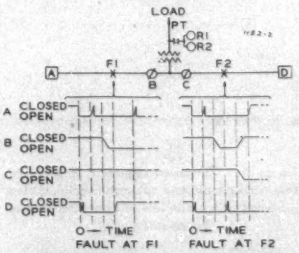
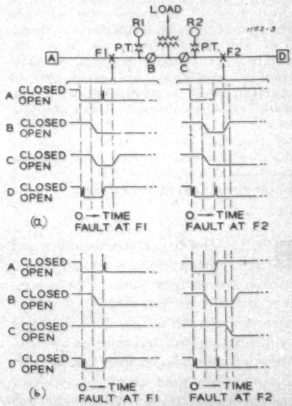


Figure 2. Operation-sequence diagram of line breakers and two automatic sectionalizing air-break switches with low side potential control

permanent faults are expected in the short section and practically all are expected in the long section. Since the airbreak switch is automatized only for opening, it is desirable that opening not take place until after some assurance of a permanent fault. For this reason at least two attempts are made to re-energize the line before the airbreak switch opens.

Figure 2 shows two airbreak switches controlled by relays *R*1 and *R*2, which also receive potential indications from the low side of power transformers. This scheme assures service to a load should a permanent fault occur on either side of the load.

Figure 3*a* shows two airbreak switches automatized for both opening and closing operations. This requires the use of potential devices connected to the line side of each airbreak switch for control. Since these switches will reclose automatically with line re-energized, less assurance is required that a fault be permanent before the switches automatically open. For this reason only one attempt at re-energizing the line is made before opening takes place. Switches *B* and *C* are identically equipped and controlled.



Figures 3a and 3b. Operation-sequence diagram of line breakers and two automatic sectionalizing air-break switches with high side potential control

They open simultaneously a definite time after initial attempt to re-energize line. After switches *B* and *C* open, breakers *A* and *D* close simultaneously; breaker *A*, closing on the fault, will reopen, and breaker *D* will remain closed. The line being re-energized to switch *C* will cause this switch to close and re-establish service.

Figure 3*b* shows two airbreak switches with equipment identical to that of the switches in figure 3*a*, but having different timing control. These switches are automatized so that only one switch is open at any given time. This scheme affords a faster means of service restoration than the scheme of figure 3*a* for faults in the *F*1 section, and slightly longer time for faults in the *F*2 section.

Need for a Quick-Resetting Reclosing Relay

To prevent possible hazards to service within a transmission system, a reclosing

relay is needed with quick resetting action following any successful reclosure. However, some time should elapse after a reclosure before permitting the device to reset quickly, as assurance that the reclosure was successful and that no permanent fault exists on the line. This time interval should be greater than the re-opening time of breaker under an existing fault condition, and its length is limited only by the permissible duty on the breaker. In no case, however, should the resetting time be extended until the device has traversed its complete reclosing cycle.

In the case of a breaker equipped with a unidirectional reclosing relay which trips on a transient fault, closes automatically and again trips on a second transient fault, the feeder customers would needlessly be without service until a subsequent reclosure point is reached. Even though this outage is momentary, important motor loads may be dropped, whereas with a quick resetting reclosing relay service would be immediately re-established upon the second tripout. In addition, if a transient tripout occurs during the timing interval between the final reclosure point and the lock-out position of a standard unidirectional reclosing relay, it will lock out without reclosing the breaker. Obviously such hazards can be serious, especially in a transmission system with isolated unattended or semi-attended substations, since it is possible for lines to be out of service or loop circuits to be open for lengthy periods when such unidirectional relays are so employed.

Likewise, on lines containing automatic sectionalizing airbreak switches and whose terminal breakers are controlled by unidirectional relays, subsequent tripouts as described above may cause these sectionalizing switches to open unnecessarily (due to loss of potential) and thereby seriously hazard service. Under these conditions the time coordination between the operations of the breakers and switches becomes disrupted.

Description of the Reclosing Relay

In view of the foregoing and the fact that automatic substations and motor operated sectionalizing switches have increased in number on the Oklahoma Gas and Electric Company system, the author designed an accurate timing, adjustable resetting, automatic reclosing relay for universal breaker application in the company's transmission system. It consists of an assembly of eleven standard telephone type relays mounted in a standard glass covered case as shown pictorially in figure 4 and schematically in figure 5. It contains no fabricated parts other than a terminal board and a mounting plate for the relays. Its principal features are:

Timer

The device contains no motor-driven gears, drum, or camshaft for interval timing. Timing is obtained by a vibrating reed relay acting in conjunction with slow-operate relays to pulse a stepping switch at intervals adjustable between 1 and 15 seconds. The vibrating reed relay *VR*, figures 4 and 5, on energization pulls-up and energizes slow-release relay *SR*, which seals in and de-energizes the *VR* relay; de-

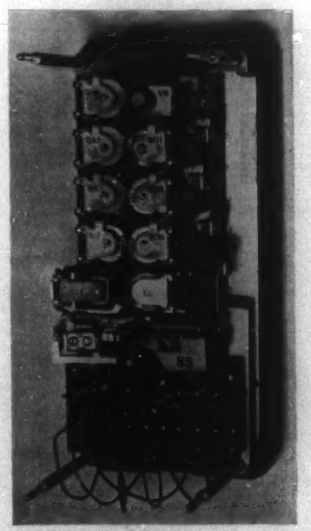


Figure 4. The reclosing relay, an assembly of 11 telephone-type relays

energization releases the reed which vibrates to rest, thus energizing (through break contacts) slow-operate relay *SO*2. Relay *SO*2 in turn energizes slow-operate relay *SO*3 to move the stepping switch one step by energizing the operating coil *SS*. Relay *SO*3 de-energizes relay *SR* which causes repetition of the timing cycle for further movements of the stepping unit. The stepping switch has 10 steps which make possible a maximum time duration of $2^1/_2$ minutes for this reclosing relay. As many as 3 breaker reclosures can be made by it, and they can be accurately spaced from 3 seconds to $1^1/_4$ minutes apart.

Variable Conditions of Breaker Closure

The recloser contains a built-in "line potential checking relay" (*QAL*) which affords choice of breaker closures on "de-energized line only," "energized line only," or "energized and/or de-energized line." By means of an external terminal connection the device can be interlocked with a synchronism-check relay for closures on "energized line in-phase only" or "de-energized line and/or energized line in-phase."

Variable Conditions of Timer Movement

By this term is meant the conditions under which the stepping switch is advanced following the initial reclosure. For most applications the "conditions of timer movement" and the "conditions of breaker closure" should be the same in order that the timer not move the stepping switch past subsequent reclosure points to the "lockout position" while the conditions of breaker reclosure are incorrect. On the other hand, when the time coordination between operations of breakers and sectionalizing switches is close it is necessary that the reclosing relays serving both terminals of the line advance together regardless of breaker closing conditions.

Quick Reset

The most salient feature of the reclosing relay is its ability to reset following successful reclosures. Reset takes place immediately after the breaker has remained closed a definite time as assurance that the fault was not permanent. Retripping of the breaker before this time expires will cause the relay to progress toward subsequent reclosing points without resetting. This definite time limit is adjustable in impulse intervals of the stepping switch independently after each reclosure. The reset feature may be omitted from any reclosure, as is sometimes desired, to limit the possible rupturing duty that may be imposed upon a breaker with limited rating.

Antipump on All Reclosures

The relay is inherently anti-pump (electrically trip free) on all reclosures, that is, for each reclosure the closing circuit to the breaker is opened immediately upon closure and cannot be re-energized until a subsequent reclosing point is reached, and only then providing the breaker is open and closing conditions satisfy the settings made on the terminal board later described. This feature is obtained by energizing the closing relay *CL* through

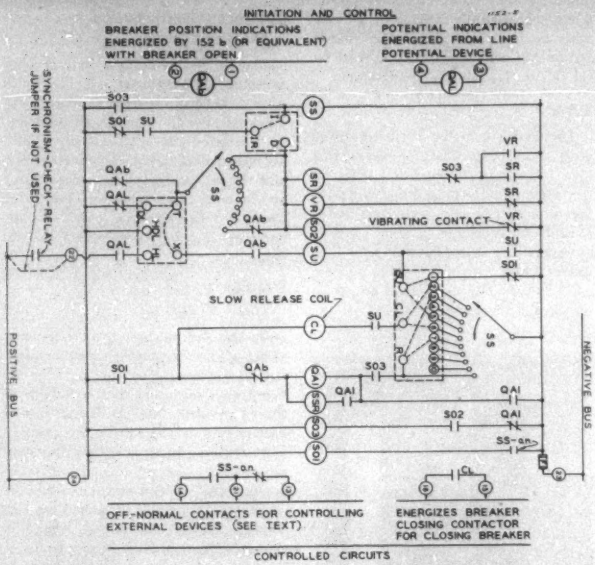

INITIATION AND CONTROL
BREAKER POSITION INDICATIONS ENERGIZED BY 152 b (OR EQUIVALENT) WITH BREAKER OPEN
POTENTIAL INDICATIONS ENERGIZED FROM LINE POTENTIAL DEVICE
SYNCHRONISM-CHECK-RELAY JUMPER IF NOT USED
POSITIVE BUS
NEGATIVE BUS
VIBRATING CONTACT
SLOW RELEASE COIL
OFF-NORMAL CONTACTS FOR CONTROLLING EXTERNAL DEVICES (SEE TEXT)
ENERGIZES BREAKER CLOSING CONTACTOR FOR CLOSING BREAKER
CONTROLLED CIRCUITS

Figure 5. Schematic diagram of internal connections of reclosing relay

contacts of the set-up relay *SU* (figures 4 and 5), which is initiated from points of the stepping switch just preceding the points of closure, and is held energized by its own contacts until dropped by the control relay *QAb* on closure of the breaker.

Setting the Relay

The pulsing intervals of the stepping unit are adjustable between 1 and 15 seconds by screws which vary the reed amplitude of the vibrating reed relay (*VR*). All other settings are made electrically by inserting plug type jumpers in proper jacks on the terminal board, figures 4 and 5. The points of the stepping switch are terminated in a row of jacks numbered 2 to 10 on the board. The number 1 jack represents the zero point or normal position of the stepping switch —being controlled by slow-operate relay *SO*1, which is operated by an off-normal contact "*SS*-on" on the stepping unit.

Directly below this row of jacks is a row of 3 binding posts, *SU*, *CL*, and *R*, from which by use of jumper connections to the row of jacks time settings are made for: (1) initiation of the set-up relay *SU*, (2) energization of the closing relay *CL*, which closes the breaker, (3) resetting of the relay. Reset is accomplished instantaneously by energization of relay *QA*1 which seals in and maintains energized the reset coil *SSR* of the stepping switch until the unit has fully reset and relay *SO*1 is de-energized by the opening of "off-normal" contact "*SS*-on." Note that resetting cannot take place unless relay *QAb* is de-energized as indication that breaker is closed.

The conditions of breaker reclosure are set by placing jumpers from binding post "*X*" to jack "*DL*" for "dead-line" closing conditions, to jack "*HDL*" for "hot and/or dead-line" (non-restricted) conditions, and to jack "*HL*" for "hot-line" conditions. Jacks *DL* and *HL* are controlled by a break and a make contact respectively of line checking relay *QAL*. If synchronism-check is desired, the external terminal stud "22" is connected in series with the contacts of the synchronism-check relay to the positive bus; otherwise this terminal stud is connected directly to the positive bus. These connections to point "*X*" establish the conditions for which the set-up relay *SU* is energized.

The conditions of timer movement are set by placing jumpers from binding post "*T*" to the same jacks as those for the conditions of closure. Such connections to point "*T*" control the conditions for which the timer relays *SR*, *VR*, and *SO*2 are energized.

Immediate or delayed initial reclosure is chosen by inserting jumper from jack "*IR*" to jack "*T*" for "immediate" reclosure, or from jack "*IR*" to jack "*D*" for "delayed" reclosure. Connection to jack "*T*" permits immediate energization of operating coil *SS* of stepping switch, and connection to jack "*D*" interposes one impulse cycle of timing relays before energization of coil *SS*.

Other Features

As can be seen from schematic connection diagram figure 5, only one breaker auxiliary switch (152*b*) is required for operation, or in many cases the reclosing relay may be controlled directly from the breaker alarm or indicating light circuits instead, since the only requirement is energization of relay *QAb* when breaker is open.

The auxiliary relay *CL* which energizes the breaker closing circuit is equipped with a vacuum contact for the high-current capacity required in energizing breaker closing contactors. Its coil is slow releasing in order to permit ample time for the breaker to latch closed without any necessary critical adjustment of the breaker auxiliary switch.

The reclosing relay can be made for operating voltages from 24 to 250 volts d-c, or a-c with a rectifier unit.

A mechanical pointer fastened to the shaft of the stepping switch indicates when the relay is locked out by pointing to line marked "*LO*" on front of stepping unit.

The relay will automatically reset upon manual closing of breaker after lockout, provided breaker remains closed for one impulse interval of timer, otherwise it will remain in the lock-out position.

For remote supervisory indication and for other external functions of control associated with reclosing of breakers, two auxiliary "off-normal" contacts (*SS*-on) are brought out to terminal studs 13, 14, and 21. In attended stations where the relay is located away from control board, remote off-normal supervision indicates relay operations to the attendant. An important control function using an off-normal contact involving fuse operations is described below.

Method of Reducing Fuse Outages

To lessen the outages caused by transient faults on multibranch-fuse circuits served through a common breaker, the Oklahoma Gas and Electric Company is using a unique automatic scheme which permits instantaneous initial tripping of the breaker for a fault at any point on the circuit. Service is immediately restored by the breaker reclosing equipment. The instantaneous opening of the breaker

interrupts transient short-circuits before the branch fuses have time to blow. Service can then be restored to the fused branch immediately, instead of waiting until a fuse can be replaced. Of course, service to the entire circuit is momentarily interrupted, but it is doubtful whether such an interruption is more serious than the voltage disturbance caused by a longer clearing time of a fuse.

In order to protect customers on unfaulted branches when a permanent fault occurs, a reclosing relay fulfilling the following requirements is needed. It must remove the instantaneous tripping relays from service prior to the immediate reclosure of the breaker so as to permit coordination between breaker time-delay relays and sectionalizing fuses, and it should hold these instantaneous relays removed from service until it has reset and again is capable of an immediate reclosure, otherwise more than a transient outage may result needlessly to all customers.

The reclosing relay herein described with its auxiliary "off-normal" contact on the stepping switch fulfills all requirements. This "off-normal" contact (figure 5, terminal studs 13 and 21) is connected in series with the instantaneous tripping relay contacts and opens this circuit upon movement of the stepping switch off-normal just before closure of the breaker. The circuit remains open until the relay is fully reset.

The reset feature of the reclosing relay for this service is as useful in preventing fuse outages as the scheme itself.

Operating Experience

The accompanying table is an analysis of operations from January 1939 through June 1941 of the line breakers which are equipped with the reclosing relay.

Under (I) above, three of the successful sectionalizing operations were accomplished within 8 seconds by equipment utilizing the scheme of figure 3b. The four "line sectionalizing failures" were in no case due to improper functioning of the reclosing relays. One was caused by a blown fuse in an airbreak, switch mechanism; one was caused by the nature of the fault—open conductor, grounded on one end and in clear on the other; one was caused by the failure of a breaker to latch closed; the fourth was caused by manual interference with the automatic reclosing relay.

		Number	Per Cent
I.	Breakers serving lines equipped with automatic sectionalizing air-break switches:		
	Line terminals equipped	7	
	Line faults	123	100
	Normal service restored, initial reclosure	101	82
	Normal service restored, second reclosure	7	6
	Normal service restored, third reclosure	6	5
	Relay lockouts	9	7
	Reset feature, beneficial	12	10
	Permanent faults	12	100
	Line correctly sectionalized	8	67
	Line sectionalizing failures	4	33
II.	Breakers serving 66 kv-loop-circuit lines:		
	Line terminals equipped	6	
	Line faults	304	100
	Normal service restored, initial reclosure	298	98
	Normal service restored, second reclosure	3	1
	Normal service restored, third reclosure	0	0
	Relay lockouts	3	1
	Reset feature, beneficial	40	13
III.	Breakers serving multi-branch-fuse circuits:		
	Line terminals equipped	1	
	Line faults	46	100
	Normal service restored, immediate reclosure	45	98
	Normal service restored, second reclosure	1	2
	Normal service restored, third reclosure	0	0
	Relay lockouts	0	0
	Reset feature, beneficial	3	6

The most important result shown by the analysis is the fact that the reset feature of the relay was beneficial in restoring service for 55 of the total 471 fault operations, that is, for approximately 12% of the faults, which faults occurred following a successful reclosure and within the total cycle of time for which the relays were set, the quick resetting action of the relay, in addition to speeding restoration of service, prevented the following possible service hazards. (Previously described under "Need for Quick Resetting Reclosing Relay.)

1. Disruption of time-sequence coordination between operations of automatic sectionalizing airbreak switches and line terminal breakers.

2. Longer than transient outages to important loads.

3. Loop circuits remaining open for lengthy periods.

4. Lockouts of reclosing relays without closing the breakers.

Conclusions

The relay meets the following requirements which are essential to successful operation of oil circuit breakers in an extensive transmission network:

1. Variable conditions of closure

2. Variable conditions of timing

3. Fast and accurate timing between closures

4. Anti-pump characteristics

5. Auxiliary off-normal contacts for external control and indications

6. Operation on either alternating or direct current

7. Quick resetting following successful reclosures

It is through the fulfillment of above requirements that the reclosing relay permits a transmission system to render maximum continuity of service. Interruptions caused by transient faults are minimized; hazards caused by untimely tripouts are eliminated; coordination between breakers and automatic sectionalizing switches is made faster and more effective; and fuse outages on certain circuits are greatly reduced. All of this has been definitely proved by 14 installations of the relay in the Oklahoma Gas & Electric Company's system over a period of $2^1/_2$ years beginning January 1939. Experience also has shown that the relay is dependable and virtually trouble free—a tribute to the versatile and highly developed relays originally created for automatic telephone systems.

Formulas for the Inductance of Rectangular Tubular Conductors

THOMAS JAMES HIGGINS
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THE formula for the inductance per unit length of two parallel conductors of rectangular cross section, obtained by using the formal expressions for the geometric mean distance of a rectangle to itself and the geometric mean distance between two rectangles with sides parallel, is exceedingly cumbersome. More than a score of logarithms and arc tangents must be evaluated when computing the inductance for a given conductor spacing and cross section. To circumvent such lengthy calculations when computing the reactance of like parallel rectangular strap conductors, Dwight[1, 2] has published curves, each plotted for a certain conductor spacing and cross section, from which the reactance can be obtained. Unless, however, the conductor spacing and the ratio of conductor thickness to breadth coincides with those values for which the curves are plotted, interpolation is necessary. Recently Roth[3] has expressed the inductance of such lines in the form of a rapidly converging series, the parameters of which are the spacing and dimensions of the conductors. Usually, a few terms of this series suffice to yield a value of inductance sufficiently accurate for all design purposes.

As regards rectangular tubular conductors, the only analytical literature is a paper by Dwight and Wang[4] giving formulas for *thin square* tubular conductors. These are derived on the assumption that the conductor walls are so thin that the sides can be considered as but line segments. The geometric mean distances for such segments are then used to calculate the inductance. Such a procedure is equivalent to asserting that the current flows solely on the surface of the conductors. It follows, then, that the values of inductance computed on this basis will be *less* than the actual values. Consequently, while these formulas suffice for many calculations on square tubular conductors, if accuracy is a desideratum of design this minimization of thickness restricts the range of application of these formulas to *very thin square* tubular conductors. Recognizing this restriction and noting, further, that commercial conductors have rounded corners, Dwight and Wang give formulas, empirically deduced, from which corrections for thickness and for rounded corners can be calculated.

The inductance of rectangular tubular conductors of appreciable thickness (and not necessarily square) can be obtained from equations given by the author[5] for the case of a line composed of two parallel conductors, the cross sections of which are geometrically similar but dimensionally different hollow rectangles. However, as these equations are implicit rather than explicit, they are ill suited to numerical computation. Yet, in light of the increasing use of rectangular tubular conductors for main bus bars, electric furnace installations, and other heavy current duties (especially feeders for batteries of welders), it is most desirable to have formulas with which one can calculate quickly the inductance for any conductor spacing or cross section. *Such formulas are derived in this paper*, it being assumed that the conductors are nonmagnetic, square cornered, of such length that end effects are negligible, and carry currents uniformly distributed over the cross sections of the individual conductors.

Although obtained through a procedure involving rather intricate analysis, the formulas themselves are simple in nature. With them a designer can calculate rapidly the inductance of a single-phase circuit composed of solid or tubular rectangular conductors; or of a three, six, or twelve-phase circuit composed of solid or tubular rectangular conductors, the axes of which lie in a plane.

I. The Formal Solution

With reference to figure 1, we seek A_1 which satisfies the differential equations

$$\nabla^2 A_1 = 4\pi w \text{ over } C_1 \tag{1}$$

$$\nabla^2 A_1 = -4\pi w \text{ over } C_4 \tag{2}$$

$$\nabla^2 A_1 = 0 \text{ over the remainder of the right half-plane} \tag{3}$$

and the boundary conditions

$$A_1 = 0 \text{ at infinity} \tag{4}$$

$$A_1 = 0 \text{ on the line } x = 0 \tag{5}$$

$$\frac{\partial A_1}{\partial y} = 0 \text{ on the line } y = 0 \tag{6}$$

The boundary conditions are obtained as follows: (4) from knowledge that the vector potential vanishes at infinity except for an arbitrary constant, taken here as zero; (5) from observation that the line $x = 0$ and the left-hand portion of the circle of infinite radius constitute, in the limit, a line of induction, whence, lines of induction being lines of constant vector potential, the vector potential is zero as on the circle at infinity; (6) from noting that the horizontal component of induction density vanishes on the line $y = 0$, or $B_x = \partial A_1/\partial y = 0$.

For the problem at hand, A_1 is an even function of y, an odd function of x. Accordingly, A_1 is expressed by the double Fourier integral

$$A_1 = (4/\pi^2) \times \int_0^\infty \int_0^\infty \int_0^\infty \int_0^\infty A_1(X, Y) \sin MX \times \cos Ny \cos NY \sin MX dX dY dN dM \tag{7}$$

the same satisfying (5) and (6) unconditionally, and (1), (2), and (3) providing $A_1(X, Y)$ or an integral containing $A_1(X, Y)$ is appropriately determined. Thus, if the double Fourier integral expressing the current density at any point in the conductors,

$$w = (4/\pi^2) \int_0^\infty \int_0^\infty \int_0^\infty \int_0^\infty w(x, y) \times \sin Mx \cos Ny \cos NY \times \sin MX \, dX dY dN dM$$

$$= (4/\pi^2) \int_0^\infty \int_0^\infty \int_0^h \int_{d-e}^{d+e} w \sin Mx \times \cos Ny \cos NY \sin Mx \, dX dY dN dM$$

$$= (8w/\pi^2) \int_0^\infty \int_0^\infty \frac{1}{MN} \sin Mx \cos Ny \times \sin Nh \sin Md \sin Me \, dN dM \tag{8}$$

is substituted in the right-hand member of

$$4(M^2 + N^2)/\pi^2 \times \int_0^\infty \int_0^\infty \int_0^\infty \int_0^\infty A_1(X, Y) \sin MX \times \cos Ny \cos NY \sin Mx \, dX dY dN dM = 4\pi w \tag{9}$$

obtained by substituting (7) in (1), we

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This paper is based upon a thesis submitted by Professor Higgins to the faculty of Purdue University in June 1941 in partial fulfillment of the requirements for the degree of doctor of philosophy.

1. For all numbered references, see list at end of paper.

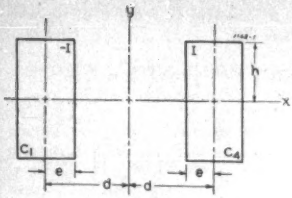

Figure 1

have, on comparing the two members of the resulting equation

$$\int_0^\infty \int_0^\infty A_1(X,Y)\cos NY\sin MX\times dXdY=8\pi w\frac{\sin Nh\sin Md\sin Me}{MN(M^2+N^2)} \quad (10)$$

Finally, substituting (10) in (7), we have for A_1

$$A_1=(32w/\pi)\int_0^\infty\frac{\sin Md\sin Me\sin Mx}{M}\times\int_0^\infty\frac{\sin Nh\cos Ny}{N(M^2+N^2)}dNdM \quad (11)$$

For the current distribution of figure 2 we have, analogously,

$$A_2=(-32w/\pi)\int_0^\infty\frac{\sin Md\sin ME\sin Mx}{M}\times\int_0^\infty\frac{\sin NH\cos Ny}{N(M^2+N^2)}dNdM \quad (12)$$

Superimposing the current distributions of figures 1 and 2 results in that of figure 3. The corresponding vector potential is

$$A=A_1+A_2 \quad (13)$$

The total electromagnetic field energy W is, by symmetry, four times that associated with the current flowing through the shaded portions of figure 3. Thus, from the usual expression, $W=\frac{1}{2}\int AwdS$, we have

$$W=2\int_0^h\int_{d-e}^{d+e}Awdxdy-2\int_0^H\int_{d-E}^{d+E}Awdxdy \quad (14)$$

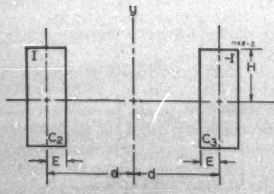

Figure 2

Substituting (11) and (12) in (13), and, in turn, (13) in (14), we have

$$W=(64w^2/\pi)\times\int_0^h\int_{d-e}^{d+e}\int_0^\infty\frac{\sin Md\sin Me\sin Mx}{M}\times\int_0^\infty\frac{\sin Nh\cos Ny}{N(M^2+N^2)}dNdMdxdy-(64w^2/\pi)\times\int_0^h\int_{d-e}^{d+e}\int_0^\infty\frac{\sin Md\sin ME\sin Mx}{M}\times\int_0^\infty\frac{\sin NH\cos Ny}{N(M^2+N^2)}dNdMdxdy-(64w^2/\pi)\times\int_0^H\int_{d-E}^{d+E}\int_0^\infty\frac{\sin Md\sin Me\sin Mx}{M}\times\int_0^\infty\frac{\sin Nh\cos Ny}{N(M^2+N^2)}dNdMdxdy+(64w^2/\pi)\times\int_0^H\int_{d-E}^{d+E}\int_0^\infty\frac{\sin Md\sin ME\sin Mx}{M}\times\int_0^\infty\frac{\sin NH\cos Ny}{N(M^2+N^2)}dNdMdxdy \quad (15)$$

These integrals are such that the order of integration can be varied as desired. Accordingly, integrating first with respect to x and then with respect to y, we have after collecting terms

$$W=(128w^2/\pi)\int_0^\infty\frac{\sin^2 Md\sin^2 Me}{M^2}\times\int_0^\infty\frac{\sin^2 Nh}{N^2(M^2+N^2)}dNdM+(128w^2/\pi)\int_0^\infty\frac{\sin^2 Md\sin^2 ME}{M^2}\times\int_0^\infty\frac{\sin^2 NH}{N^2(M^2+N^2)}dNdM-(256w^2/\pi)\times\int_0^\infty\frac{\sin^2 Md\sin ME\sin Me}{M^2}\times\int_0^\infty\frac{\sin NH\sin Nh}{N^2(M^2+N^2)}dNdM \quad (16)$$

Now[6]

$$\int_0^\infty\frac{\sin NH\sin Nh}{N^2(M^2+N^2)}dN=\frac{\pi}{2M^2}(MH-\epsilon^{-Mh}\sinh MH) \quad (17)$$

Substituting appropriately in (16), we have

$$W=64w^2\int_0^\infty\frac{\sin^2 Md\sin^2 Me}{M^3}\times(Mh-\epsilon^{-Mh}\sinh Mh)dM+64w^2\int_0^\infty\frac{\sin^2 Md\sin^2 ME}{M^3}\times(MH-\epsilon^{-MH}\sinh MH)dM-128w^2\int_0^\infty\frac{\sin^2 Md\sin ME\sin Me}{M^3}\times(MH-\epsilon^{-Mh}\sinh MH)dM \quad (18)$$

The third integral in (18) can be written as the sum of two integrals, such that W is expressed as the sum of four like integrals. Doing so, we have

$$W=64w^2\int_0^\infty\frac{\sin^2 Md\sin^2 Me}{M^3}\times(Mh-\epsilon^{-Mh}\sinh Mh)dM+64w^2\int_0^\infty\frac{\sin^2 Md\sin^2 ME}{M^3}\times(MH-\epsilon^{-MH}\sinh MH)dM-128w^2\int_0^\infty\frac{\sin^2 Md\sin ME\sin Me}{M^3}\times\left[\frac{M(h+H)}{2}-\epsilon^{-\frac{M(h+H)}{2}}\sinh\frac{M(h+H)}{2}\right]dM+128w^2\int_0^\infty\frac{\sin^2 Md\sin ME\sin Me}{M^3}\times\left[\frac{M(h-H)}{2}-\epsilon^{-\frac{M(h-H)}{2}}\sinh\frac{M(h-H)}{2}\right]dM \quad (19)$$

Each integral of (19) is of the form

$$\frac{\pi}{2}f_1(x_1,x_2,x_3,x_4)-\frac{1}{2}f_2(x_1,x_2,x_3,x_4,y) \quad (20)$$

As shown in the appendix

$$f_1=\int_0^\infty\frac{1}{M^4}\sin Mx_1\sin Mx_2\sin Mx_3\times\sin Mx_4\,dM=\frac{\pi}{32^4}\sum_{i=1}^{8}(-1)^p|k_i{}^3| \quad (21)$$

k_i designating any one of the eight possible terms to be formed from

$$(x_1\pm x_2\pm x_3\pm x_4)$$

by arbitrary selection of the plus and minus signs, while p is the number of minus signs in k_i.

For f_2 we have

$$f_2=2\int_0^\infty\frac{1}{M^3}\sin Mx_1\sin Mx_2\sin Mx_3\times\sin Mx_4\epsilon^{-\frac{My}{2}}\sinh\frac{My}{2}dM=\frac{1}{192}\sum_{i=1}^{8}(-1)^pF(k_i,y) \quad (22)$$

where k_i and p have the same significance as in (21), and

$$F(k_i, y) = (k_i^4 - 6y^2k_i^2 + y^4) \log (k_i^2 + y^2)^{1/2} + 4yk_i(k_i^2 - y^2) \tan^{-1}(k_i/y) - k^4 \log |k_i| \quad (23)$$

The fifth column of table I contains the values of k_i used in evaluating the first two integrals in (19), while those for the second two integrals of (19) are in the sixth column.

Defining new variables, $r=2e$, $R=2E$, $s=2h$, $S=2H$, $D=2d$, and $t=e-E=h-H$, evaluating each integral of (19) by means of (21) and (22), and collecting terms, we have for the terms of (19) taken in order

$$W = w^2\{W(r, s) + W(R, S) - 2[W(R+t, S+t) - W(t, S+t)] + 2[W(R+t, t) - W(t, t)]\} \quad (24)$$

where $W(r, s)$ is defined by

$$W(r, s) = 1/4[2F(D, s) - F(D+r, s) - F(D-r, s) + 2F(r, s) - 2F(0, s) + 4sr^2(3D-r)] \quad (25)$$

Collecting the terms of (24), we have

$$W = w^2[W(r, s) + W(R, S) + 2W(t, S+t) + 2W(R+t, t) - 2W(R+t, S+t) - 2W(t, t)] \quad (26)$$

The energy W being known in terms of the dimensions and spacings of the conductors, the inductance can be obtained at once from the usual formula, $W = 1/2LI^2$. Hence

$$L = 2W/w^2(rs - RS)^2 \text{ abhenries per centimeter of line length} \quad (27)$$

If $R=S=0$ we have solid conductors, and (27) becomes

$$L = 2W(r, s)/(wrs)^2 \text{ abhenries per centimeter of line length} \quad (28)$$

The 60-cycle reactance per thousand feet of conductor is obtained by multiplying L by 5.74×10^{-6}.

II. Series Expressions for L

We turn now to finding series expansions which enable one to calculate quickly each of the terms of (26). Expanding (25) in powers of r, we obtain

$$W(r, s) = \frac{1}{6}\left[2F(r, s) - 2F(0, s) + 4sr^2(3D-r) - r^2\frac{\partial^2 F(D, s)}{\partial D^2} - \frac{r^4}{2\cdot 3!}\frac{\partial^4 F(D, s)}{\partial D^4} - \frac{r^6}{3\cdot 5!}\frac{\partial^6 F(D, s)}{\partial D^6} - \dots\right] \quad (29)$$

The details of the expansion and expressions for the various derivatives, in terms of the dimensions and spacing of the conductors, are given in the appendix. Substituting appropriately in (29) and collecting terms, we have

$$W(r, s) = 2r^2\left\{s^2\left[\frac{7}{12} + \frac{1}{2}\log\frac{D^2+s^2}{r^2+s^2}\right] - \left[\frac{D^2}{2} + \frac{r^2}{12}\right]\log\frac{D^2+s^2}{D^2} + \frac{s^4}{12r^2}\log\frac{s^2+r^2}{s^2} + \frac{r^2}{12}\log\frac{r^2+s^2}{r^2} + 2sD\tan^{-1}(s/D) - \frac{2}{3}rs\tan^{-1}(s/r) - \frac{2s^3}{3r}\tan^{-1}(r/s) - \frac{r^4}{180}\left[\frac{1}{D^2} - \frac{D^2-s^2}{(D^2+s^2)^2}\right] - \frac{r^6}{1{,}680}\times\left[\frac{1}{D^4} - \frac{(D^2-s^2)^2 - 4D^2s^2}{(D^2+s^2)^4}\right] - \frac{r^8}{7{,}560}\times\left[\frac{1}{D^6} - \frac{(D^2-s^2)^3 - 12s^2D^2(D^2-s^2)}{(D^2+s^2)^6}\right] - \dots\right\} \quad (30)$$

If $r<s$, (30) can be put in a more convenient form. Utilizing the power series for $\log(1+x)$ and $\tan^{-1}x$, we have after expanding appropriately in (30) and collecting terms

$$W(r, s) = 2r^2\left\{\frac{s^2}{2}\log\frac{D^2+s^2}{s^2} - \frac{D^2}{2}\log\frac{D^2+s^2}{D^2} + 2sD\tan^{-1}(s/D) - \pi rs/3 + r^2\left[\frac{25}{75} - \frac{1}{12}\log\frac{r^2(D^2+s^2)}{s^2D^2}\right] - \frac{r^4}{180}\left[\frac{1}{D^2} - \frac{D^2-s^2}{(D^2+s^2)^2} - \frac{1}{s^2}\right] - \frac{r^6}{1{,}680}\times\left[\frac{1}{D^4} - \frac{(D^2-s^2)^2 - 4D^2s^2}{(D^2+s^2)^4} + \frac{1}{s^4}\right] - \dots\right\} \quad (31)$$

If $r<s$ and, in addition, $D>s$, we can expand (31) still further obtaining

$$W(r, s) = 2r^2s^2\left\{\log\frac{D}{s} + \frac{r^2}{s^2}\times\left[\frac{25}{72} - \frac{1}{12}\log\frac{r^2(D^2+s^2)}{s^2D^2}\right] + \frac{3}{2} - \frac{\pi r}{3s} + \frac{1}{12}\frac{s^2}{D^2} - \frac{1}{60}\frac{s^4}{D^4} + \frac{1}{168}\frac{s^6}{D^6} - \dots - \frac{1}{180}\frac{r^4}{s^4}\times\left[\frac{s^2}{D^2} - \frac{s^2D^2 - s^4}{(D^2+s^2)^2} - 1\right] - \dots\right\}$$

$$= 2r^2s^2\left\{\log\frac{1}{m} + n^2\times\left[\frac{25}{72} - \frac{1}{12}\log n^2(1+m^2)\right] + \frac{3}{2} - \frac{\pi r}{3s} + \frac{m^2}{12} - \frac{m^4}{60} + \frac{m^6}{168} - \dots - \frac{n^4}{180}\times\left[m^2 - \frac{m^2 - m^4}{(1+m^2)^2} - 1\right] - \dots\right\} \quad (32)$$

where $m=s/D$ and $n=r/s$.

If, however, $r<s$ and $s>D$, we have from (31)

$$W(r, s) = 2r^2s^2\left\{\pi m + \left(\log m - \frac{3}{2}\right)m^2 - \frac{m^4}{12} + \frac{m^6}{60} - \frac{m^8}{168} + \dots - \frac{\pi n}{3} + n^2\times\left[\frac{25}{72} - \frac{1}{12}\log n^2\left(1 + \frac{1}{m^2}\right)\right] - \frac{n^4}{180}\times\left[\frac{1}{m^2} - \frac{m^2-1}{(m^2+1)^2} - 1\right] - \dots\right\} \quad (33)$$

where now $m=D/s$ and $n=r/s$.

If $r>s$, we have from (30)

$$W(r, s) = 2r^2s^2\left\{\frac{1}{2}\log\frac{D^2+s^2}{r^2} - \frac{D^2}{2s^2}\log\frac{D^2+s^2}{D^2} + \frac{2D}{s}\tan^{-1}(s/D) - \frac{r^2}{12s^2}\log\frac{D^2+s^2}{D^2} - \frac{\pi s}{3r} - \frac{s^2}{6r^2}\left[\log\frac{s}{r} - \frac{25}{12}\right] + \frac{1}{180}\frac{s^4}{r^4} - \frac{1}{1{,}680}\frac{s^6}{r^6} + \dots - \frac{1}{180}\frac{r^4}{s^4}\times\left[\frac{1}{D^2} - \frac{D^2-r^2}{(D^2+r^2)^2}\right] - \dots\right\} \quad (34)$$

If $r>s$ and, in addition, $D>r$, we have from (34)

$$W(r, s) = 2r^2s^2\left\{\log\frac{D}{r} - \frac{1}{12n^2}\log(1+m^2) - \frac{n^2}{6}\log n + \frac{3}{2} - \frac{\pi n}{3} + \frac{25n^2}{72} + \frac{n^4}{180} - \frac{n^6}{1{,}680} + \dots + \frac{m^2}{12} - \frac{m^4}{60} + \frac{m^6}{168} - \dots - \frac{1}{180n^4}\left[m^2 - \frac{s^2(D^2-r^2)}{(D^2+r^2)^2}\right] - \dots\right\} \quad (35)$$

where $m=s/D$ and $n=s/r$.

If $r=s$, we obtain from (30)

$$W(r, s) = 2r^4\left\{\frac{1}{2}\log\frac{D^2+r^2}{r^2} - \left[\frac{D^2}{2r^2} + \frac{1}{12}\right]\log\frac{D^2+r^2}{D^2} + \frac{2D}{r}\tan^{-1}(r/D) - 1.579393 - \frac{r^2}{180}\left[\frac{1}{D^2} - \frac{D^2-r^2}{(D^2+r^2)^2}\right] - \frac{r^4}{1{,}680}\left[\frac{1}{D^4} - \frac{(D^2-r^2)^2 - 4D^2r^2}{(D^2+r^2)^4}\right] - \dots\right\} \quad (36)$$

If $r=s$ and, in addition, $D>r$, we have from (36)

$$W(r, s) = 2r^4\left\{0.805087 - \log m + \frac{m^4}{40} - \frac{11}{504}m^6 + \frac{13}{720}m^8 - \dots - \frac{m^2}{180}\left[1 - \frac{1-m^2}{(1+m^2)^2}\right] - \frac{m^4}{1{,}680}\times\left[1 - \frac{(1-m^2)^2 - 4m^2}{(1+m^2)^4}\right] - \dots\right\} \quad (37)$$

where $m=r/D$.

III. Identification of the Terms of (24)

As (28) can be written in the form

$$L=4\log(D_{14}/D_{11})=2W(r,s)/(wrs)^2 \quad (38)$$

where D_{14} is the geometric mean distance between C_1 and C_4, while D_{11} is the geometric mean distance of C_1 or C_4 to itself, these latter can be expressed as functions of the terms of (25). Our expressions are somewhat simplified if we introduce the new function

$$G(k_1, y)=F(k_1, y)-2\pi y|k_1|(k_1^2-y^2) \quad (39)$$

Comparison of $W(r, s)$ with expressions for $\log D_{14}$ and $\log D_{11}$ given elsewhere[6] reveals that

$$12r^2s^2\log D_{14}=2G(D,s)-G(D+r,s)-G(D-r,s)-25r^2s^2 \quad (40)$$

$$12r^2s^2\log D_{11}=-2G(r,s)+2G(0,s)+4\pi rs^3-25r^2s^2 \quad (41)$$

Similarly, from $W(R, S)$ we have

$$12R^2S^2\log D_{23}=2G(D,S)-G(D+R,S)-G(D-R,S)-25R^2S^2 \quad (42)$$

$$12R^2S^2\log D_{33}=-2G(R,S)+2G(0,S)+4\pi RS^3-25R^2S^2 \quad (43)$$

Like (28) written in the form of (38), we have[5] for (27)

$$L=\frac{4}{(rs-RS)^2}(r^2s^2\log D_{14}+R^2S^2\log D_{23}+2rsRS\log D_{12}-r^2s^2\log D_{11}-R^2S^2\times\log D_{22}-2rsRS\log D_{13}) \quad (44)$$

Substituting (26) in (27) and comparing the resulting expression with (44), it follows that the as yet unidentified members of (26) must equal

$$-4rsRS\log D_{13}+4rsRS\log D_{12} \quad (45)$$

Obviously, of the unidentified terms of (26), those containing D comprise the first component of (45), those not containing D comprise the second component of (45). We have, then,

$$12rsRS\log D_{13}=G(D+t,S+t)-25rsRS-G(D-t,S+t)-G(D+R+t,S+t)-G(D-R-t,S+t)-G(D+t,t)-G(D-t,t)+G(D+R+t,t)+G(D-R-t,t) \quad (46)$$

$$12rsRS\log D_{12}=2G(t,S+t)-2G(R+t,S+t)+4\pi R(S+t)^3-2G(t,t)+2G(R+t,t)-4\pi Rt^3-25rsRS \quad (47)$$

where $(D-R-t)>0$.

It is evident that (40) to (47) inclusive are of particular value: with them one can calculate the inductance or reactance of any arrangement of like solid or tubular busbars, the axes of which lie in a plane. For as detailed in most texts on transmission theory, if there are n conductors constituting a polyphase circuit, the reactance of an individual wire (for example, wire a) is given by

$$x_a=0.2794\sum_{j=1}^{n}(I_j/I_a)\log(1/D_{ja})\ \text{ohms per mile at sixty cycles}$$

where

$$\sum_{j=1}^{n}I_j=0$$

Or again, if n conductors constitute a single-phase circuit, the inductance is given by

$$L=\sum_{j=1}^{n}\sum_{k=1}^{n}(-2/I^2)I_jI_k\log D_{jk}\ \text{abhenries per centimeter of line}$$

IV. An Illustrative Problem

As an illustration of the rapidity of convergence of the formulas developed in section III, we now calculate the reactance of a line composed of square tubular conductors. We use the dimensional data of a like problem to be found in the previously mentioned paper of Dwight and Wang,[4] and thus simultaneously determine the magnitude of the minimization in the basic formula presented therein, the same being due to neglecting the thickness of the conductors when deriving this formula, and the accuracy of the formula given for correcting for the effect of thickness. The data follow:

$r=s=2.5$ inches; $t=0.5$ inch; $D=10$ inches;
$f=60$ cycles per second;
$X=0.0443$ ohm per thousand feet of conductor;
$L=3.85$ abhenries per centimeter of conductor (calculated from X).

For the data given, we have from (26)

$$W/w^2=W(2.5,2.5)+W(1.5,1.5)+2W(0.5,2)+2W(2,0.5)-2W(2,2)-2W(0.5,0.5) \quad (48)$$

Thus, to determine W/w^2 each of the terms of (48) must be calculated. From (37) we have for the terms taken in order:

$$W(2.5,2.5)=78.125(0.805087+1.386294+0.0000977-0.0000589)=171.203$$

$$W(2,2)=32(0.805087+1.609438+0.000040-\ldots-0.000025)=77.264$$

$$W(1.5,1.5)=10.125(0.805087+1.897120+0.000012-\ldots-0.000008)=27.359$$

$$W(0.5,0.5)=0.125(0.805087+2.995732+0.000000-\ldots-0.000000)=0.475$$

From (32) we have

$$W(0.5,2)=2(1.609438+0.035875+1.500000-0.261799+0.003333-0.000027+\ldots+0.000022+\ldots)=5.774$$

From (35) we have

$$W(2,0.5)=2(1.609438-0.003329+0.014441+1.500000-0.261800+0.021703+0.000022-\ldots+0.000283-\ldots-0.000026)=5.761$$

The computation necessary to obtain each of these values of $W(x, y)$ was performed on an automatic calculating machine. As a check on both the computation and the series expansions, each value of $W(x, y)$ was then computed independently from (30). Agreement of the first five digits was interpreted as verification of the expansion and the first computations.

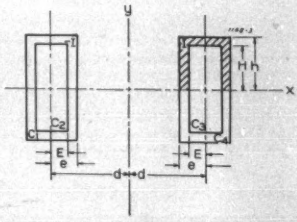

Figure 3

Substituting in (48) as indicated, we obtain

$$W/w^2=171.203+27.359+11.547+11.522-154.528-0.950=66.153$$

From (27) we have for the inductance

$$L=66.153/(6.25-2.25)^2=4.135\ \text{abhenries per centimeter of conductor}$$

Multiplying L by $120\pi/10^9$ we obtain the reactance,

$$X=496.1\pi/10^9\ \text{ohm per centimeter of conductor}$$

Converting to more suitable units, we have

$$X=496.1\pi\times2.54\times12\times10^3/10^9=0.0475\ \text{ohm per thousand feet of conductor}$$

Comparing this with the uncorrected value given by Dwight and Wang—namely, 0.0443 ohm per thousand feet of conductor, uncorrected—we find that

our value is 0.0032 ohm per thousand feet larger; or, the difference due to neglecting the thickness of the conductor is, in this case, 6.7 per cent. If the conductor were larger with correspondingly thicker walls, the per cent difference would probably be greater.

For this problem Dwight and Wang obtain from their correction formula 0.0026 ohm per thousand feet increase due to thickness. Accordingly, adding this value to the original value yields 0.0469 ohm per thousand feet of conductor. The difference is now but 0.0006 ohm per thousand feet of conductor. Accordingly, in view of this close agreement one might conjecture that in calculating the reactance of *identical, square* tubular conductors for purposes other than wherein extreme accuracy is required, that so far as time of computation is concerned the simpler formulas of Dwight and Wang can be used to the advantage of those given in this paper. If, however, the conductors are other than *both* square and identical the formulas of this paper must be used perforce.

A glance at the individual values of $W(x, y)$ will reveal the extreme rapidity with which they converge. As only three decimal places were used in calculating W/w^2 from (48), it would have been necessary to have computed only the first two terms in each of $W(2.5, 2.5)$, $W(1.5, 1.5)$, $W(2, 2)$, and $W(0.5, 0.5)$. Likewise, several terms could have been omitted in $W(2, 0.5)$ and $W(0.5, 2)$.

Appendix

I. Determination of the Integrals f_1 and f_2

We can transform f_2 as follows:

$$2=\int_0^\infty \frac{\sin Mx_1 \sin Mx_2 \sin Mx_3 \sin Mx_4}{M^3}\times \frac{e^{-My}-e^{-M}}{\sinh \frac{M}{2}}\,dM$$

$$=\int_0^\infty \frac{\sin Mx_1 \sin Mx_2 \sin Mx_3 \sin Mx_4}{M^3}\times (1-e^{-M(y-1)})\,dM$$

$$=\int_0^y\int_0^\infty \frac{\sin Mx_1 \sin Mx_2\times \sin Mx_3 \sin Mx_4}{M^4}e^{-My}\,dM\,dy$$

Substituting the value of the infinite integral,[7] we have

$$f_2=\int_0^y \frac{1}{3!2^3}\sum_{i=1}^{8}(-1)^p\left[(k_i^3-3yk_i)\times \tan^{-1}\frac{k_i}{y}-(3yk_i^2-y^3)\log(k_i^2+y^2)^{1/2}\right]dy$$

Table I. Values of K_i for Evaluating Equation 19

x_1	x_2	x_3	x_4	k_i: $x_2=x_3=d$ $x_1=x_4=e$	k_i: $x_1=x_2=d$ $x_3=x_4=e$; $x_i=E$
+	+	+	+	$2d+2e$	$2d+e+E$
+	+	−	−	$2d-2e$	$2d-e-E$
+	+	+	−	$2d$	$2d+e-E$
+	−	+	+	$2d$	$2d-e+E$
+	−	+	−	$2e$	$e+E$
+	−	−	−	$-2e$	$-(e+E)$
+	−	+	−	0	$e-E$
+	−	−	+	0	$-(e-E)$

k_i designating any one of the eight possible terms formed from the member $(x_1 \pm x_2 \pm x_3 \pm x_4)$ by arbitrary selection of the plus and minus signs, while p is the number of minus signs in k_i. Integrating and collecting terms, we obtain

$$f_2=\frac{1}{4!2^3}\sum_{i=1}^{8}(-1)^p\left[(k_i^4-6yk_i^2+y^4)\times \log(k_i^2+y^2)^{1/2}+4yk_i(k_i^2-y^2)\tan^{-1}\frac{k_i}{y}-k_i^4\log|k_i|\right]$$

$$=\frac{1}{192}\sum_{i=1}^{8}(-1)^pF(k_i, y)$$

where $F(k_i, y)$ stands for the expression within the brackets.

Noting that

$$f_1=\int_0^\infty \frac{\sin Mx_1 \sin Mx_2 \sin Mx_3 \sin Mx_4}{M^4}dM$$

$$=\lim_{y\to 0_+}\int_0^\infty e^{-My}\times \frac{\sin Mx_1 \sin Mx_2 \sin Mx_3 \sin Mx_4}{M^4}dM$$

we obtain on substituting for the infinite integral

$$f_1=\lim_{y\to 0_+}\frac{1}{3!2^3}\sum_{i=1}^{8}(-1)^p\left[(k_i^3-3y^2k_i)\times \tan^{-1}\frac{k_i}{y}-(3yk_i^2-y^3)\log(k_i^2+y^2)^{1/2}\right]$$

$$=\frac{1}{3!2^3}\sum_{i=1}^{8}(-1)^p\frac{\pi}{2}|k_i^3|$$

II. Expansion of W(r, s) in a Power Series

By definition

$$W(r, s)=1/8[2F(D, s)-F(D+r, s)-F(D-r, s)+2F(r, s)-2F(0, s)+4\pi r^3 s(3D-r)]$$

Now

$$K(x, s)=2F(D, s)-F(D+r, s)-F(D-r, s)$$

considered as a function of x alone, can be expanded in a power series about the point $x=D$. Accordingly, by Taylor's theorem we have

$$K(x, s)=-r\frac{\partial^3 F(D, s)}{\partial D^3}-\frac{r^4}{2\cdot 3!}\frac{\partial^4 F(D, s)}{\partial D^4}-\frac{r^6}{3\cdot 5!}\frac{\partial^6 F(D, s)}{\partial D^6}-\cdots$$

where

$$F(D, s)=1/8(D^4-6D^2s^2+s^4)\log(D^2+s^2)-D^4\log D+4(sD^3-Ds^3)\tan^{-1}\frac{D}{s}$$

$$\frac{\partial F(D, s)}{\partial D}=(2D^3-6Ds^2)\log(D^2+s^2)-4D^3\times \log D+4(sD^2-s^3)\tan^{-1}\frac{D}{s}-3Ds^2$$

$$\frac{\partial^2 F(D, s)}{\partial D^2}=6(D^2-s^2)\log(D^2+s^2)-12D^2\times \log D+24Ds\tan^{-1}\frac{D}{s}-7s^2$$

$$\frac{\partial^3 F(D, s)}{\partial D^3}=12D\log(D^2+s^2)-24D\log D+24s\tan^{-1}\frac{D}{s}$$

$$\frac{\partial^4 F(D, s)}{\partial D^4}=12\log(D^2+s^2)-24\log D$$

$$\frac{\partial^5 F(D, s)}{\partial D^5}=-\frac{24s^2}{D(D^2+s^2)}$$

$$\frac{\partial^6 F(D, s)}{\partial D^6}=24\left[\frac{1}{D^2}-\frac{D^2-s^2}{(D^2+s^2)^2}\right]$$

$$\frac{\partial^7 F(D, s)}{\partial D^7}=48\left[-\frac{1}{D^3}-\frac{-D^2+3Ds^2}{(D^2+s^2)^3}\right]$$

$$\frac{\partial^8 F(D, s)}{\partial D^8}=144\left[\frac{1}{D^4}-\frac{(D^2-s^2)^2-4s^2D^2}{(D^2+s^2)^4}\right]$$

$$\frac{\partial^9 F(D, s)}{\partial D^9}=576\left[-\frac{1}{D^5}-\frac{-D^5+10D^3s^2-5Ds^4}{(D^2+s^2)^5}\right]$$

$$\frac{\partial^{10} F(D, s)}{\partial D^{10}}=2,880\left[\frac{1}{D^6}-\frac{(D^2-s^2)^3-12s^2D^2(D^2-s^2)}{(D^2+s^2)^6}\right]$$

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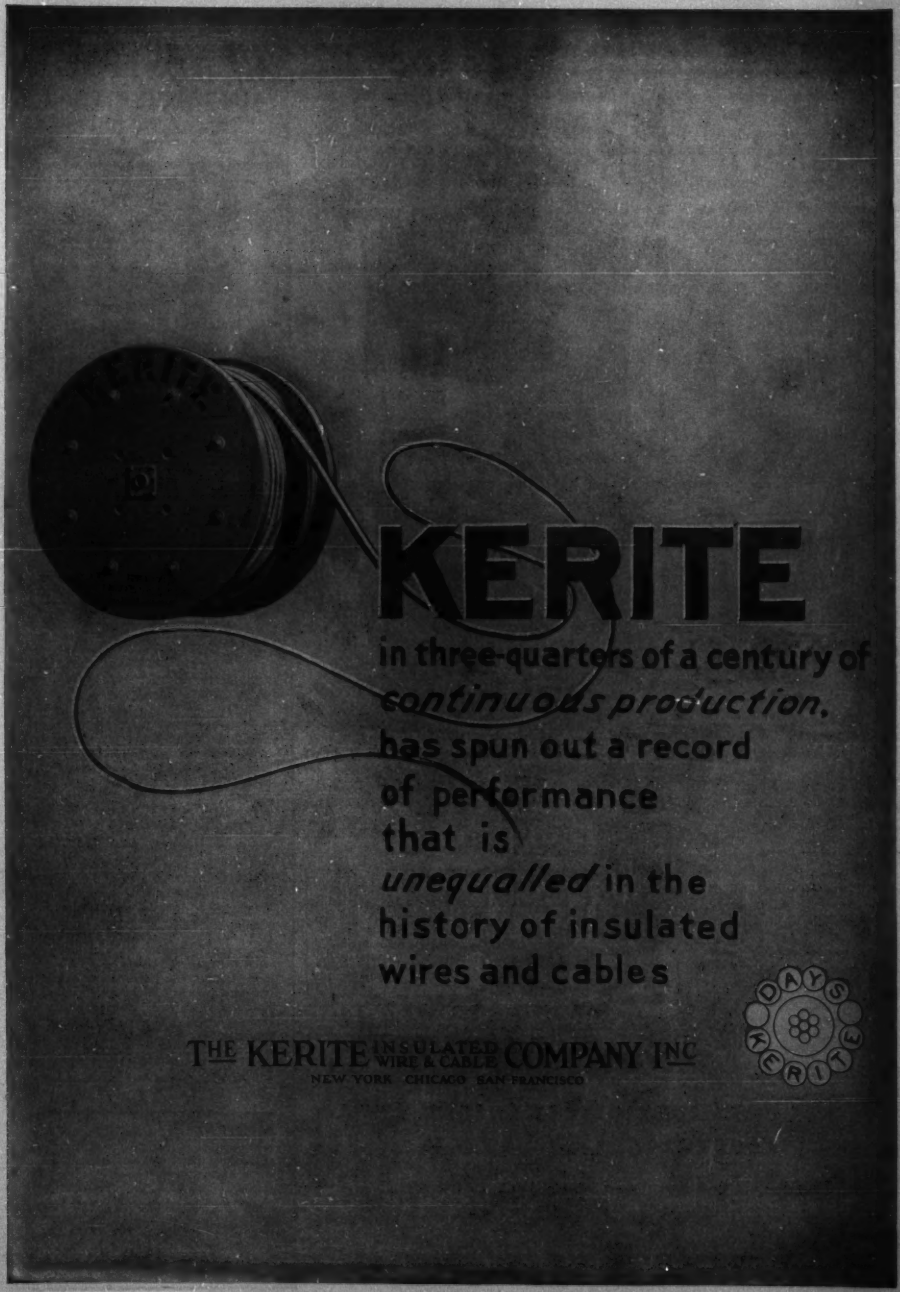
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Motors.—Bulletin B6052-B, 8 pp. Describes the complete line of "Lo-Maintenance" motors in ratings from ¼ to 75 hp; open, enclosed and splashproof types; a-c and d-c. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Control Products Index.—Bulletin 585. A condensed-index covering air-operated and electrically-operated automatic control instruments, recording and indicating instruments; telemetering instruments for recording and remote automatic control, and engineering services. The Bristol Co., Waterbury, Conn.

Small Motors.—Folder F-8623, 8 pp. Describes small motors from 1/6 to 1/2 horsepower, 145 frame size, for general use. The standard parts making available more than 5,000 combinations of type, rating, and mounting are illustrated. Charts show motor characteristics plotting per cent synchronous speed against per cent full-load torque. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

Lamp Resistor.—Bulletin 26. Describes resistor, type K-40878, for use with six watt T-5 fluorescent lamps, on either alternating or direct current with a manual momentary contact starting switch. When operating the lamps on 120-volt circuits these resistors eliminate the need of an auxiliary. The resistor unit can be mounted in any standard fixture or wiring trough, and is insulated for 15,000 volts to ground. Ward Leonard Electric Co., Mount Vernon, N. Y.

Industrial Control Equipment.—Catalog 8301, 56 pp. Describes and illustrates 44 industrial controls and safeguards such as temperature controllers, pressure controllers, humidity controllers, float switches, combustion safeguards, etc. Complete specifications and informative details are given for all types. The first few pages contain a primer of automatic control. The three classes of such control,—electric, pneumatic and combined electric and pneumatic are fully covered. The Brown Instrument Co., Wayne & Roberts Aves., Philadelphia, Pa.

Fuse Links.—Bulletin 104, 8 pp. Describes series 100-E and 50-E universal fuse links, designed to comply with new NEMA standards. Other fuse links for cutouts are also covered. Contains considerable technical information and includes transformer fusing chart and fuse coordination table with directions for use. W. N. Matthews Corp., 3700 Forest Park Blvd., St. Louis.

Transformers.—Bulletin GEA-3650, 16 pp. Describes a complete line of outdoor type current and potential transformers of 15 kv and below. The bulletin is conveniently made up with accordion-fold pages, which allow insulation characteristics, accuracy classifications, ratings, and prices of the various units to be seen at a glance by spreading the contents out flat. General Electric Co., Schenectady, N. Y.

Analyzing Plate Solutions.—Booklet 48 pp. Gives simple and practical methods of analyzing many electroplating solutions, which may be followed by those without extensive chemical training. Contains reference tables and electrochemical data pertaining to the important metals. Methods of determining thickness of deposits at various times are described. Hanson-Van Winkle-Munning Co., Matawan, N. J.

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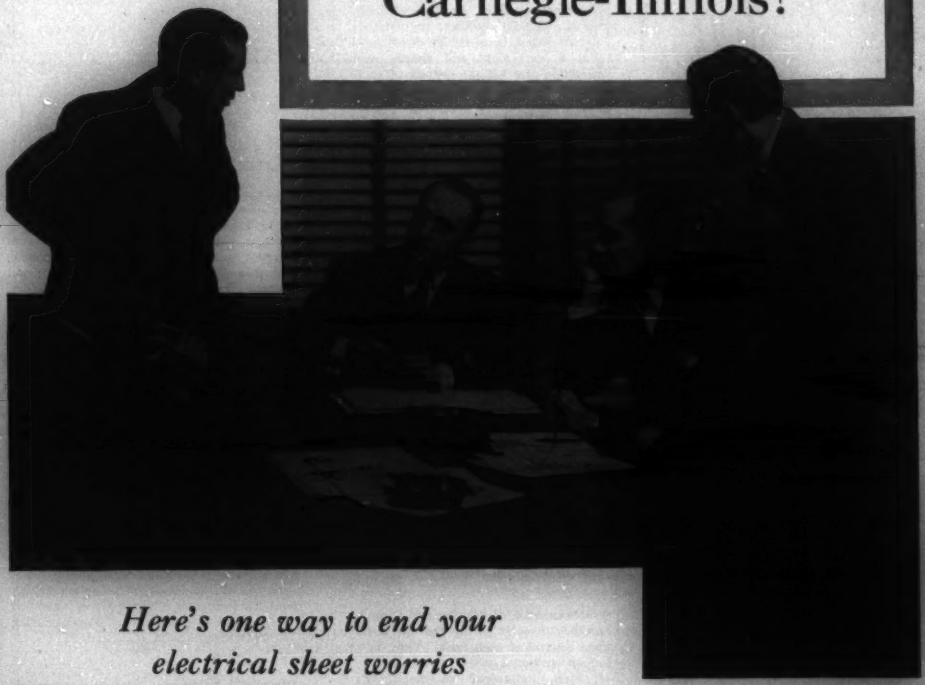

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(Continued on p. 18)

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(Continued from p. 16

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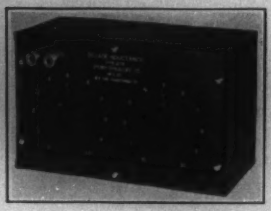

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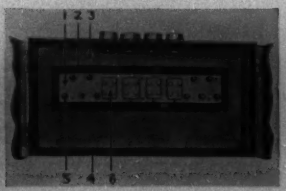

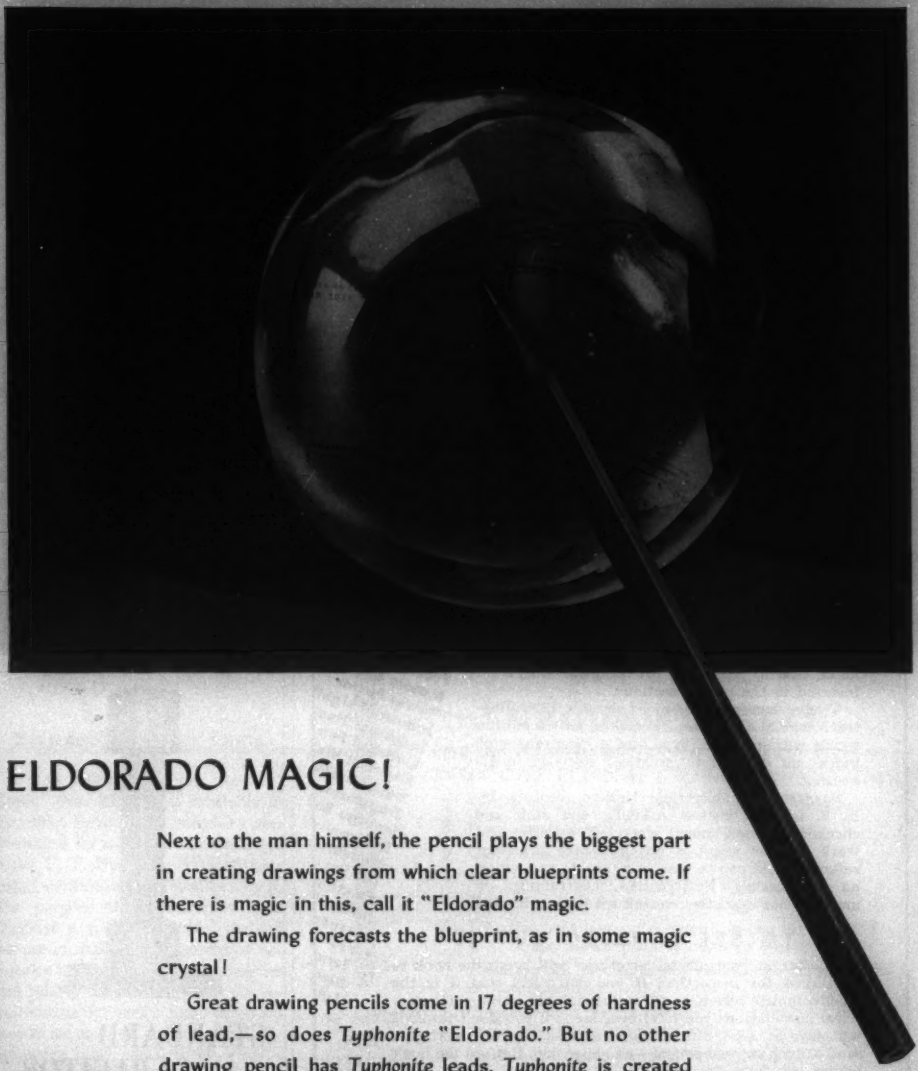

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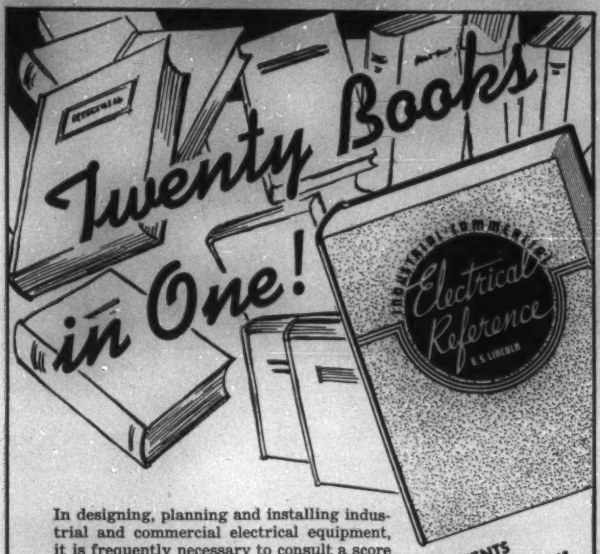

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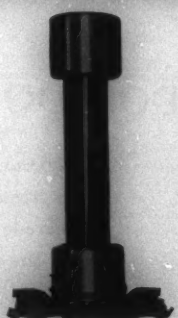

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NO. 9

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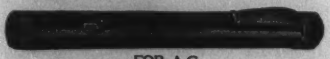

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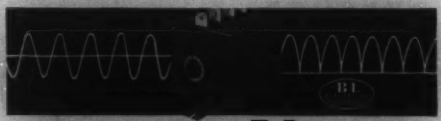

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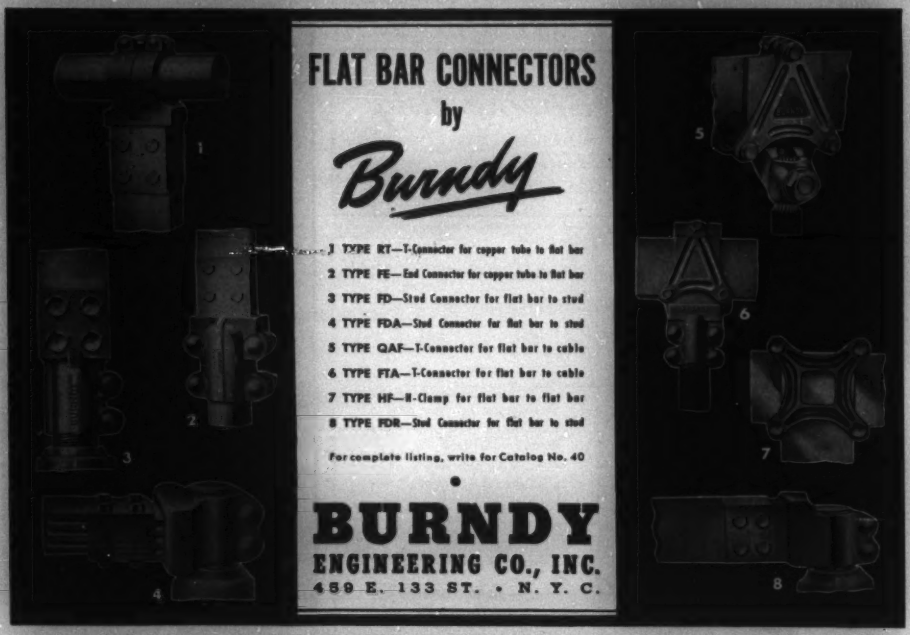
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• Last Christmas Eve and Day the wires were jammed. The switchboards were manned by regular and extra operators working all through the holiday. Long Distance telephone calls were three, five and at some places *eight* times normal.

We're glad so many folks want to exchange friendly greetings across the miles at Christmas — but sorry that, because of it, we can't supply service as good as usual.

We expect the biggest rush of calls we've ever had this coming Christmas. We'll do our best to prepare for it. But some calls will be slow. Some may not be completed. For these, we ask your patience and understanding. . . . *Thank you, and Merry Christmas!*

BELL TELEPHONE SYSTEM

IT'S the way Ohmite Rheostats are designed and built that insures permanently smooth, close control in the most critical Industrial and Defense applications.

Every turn of wire is a separate resistance step, wound on a solid porcelain core, locked in place and insulated by Ohmite vitreous enamel. There is nothing to char, shrink, shift or deteriorate. Universal mounted self-lubricating metal-graphite contact brush assures perfect contact with negligible wear on the wire.

There are ten wattage sizes, in standard or special designs, from 25 watts to 1000 watts, from 1⁹/₁₆″ to 12″ diameter. Many stock resistance values. Special variations produced to your specifications or engineered for you.

Write on company letterhead for your copy of complete, helpful, 96-page Catalog and Engineering Manual No. 40.

OHMITE MFG. CO., 4803 Flournoy St., Chicago

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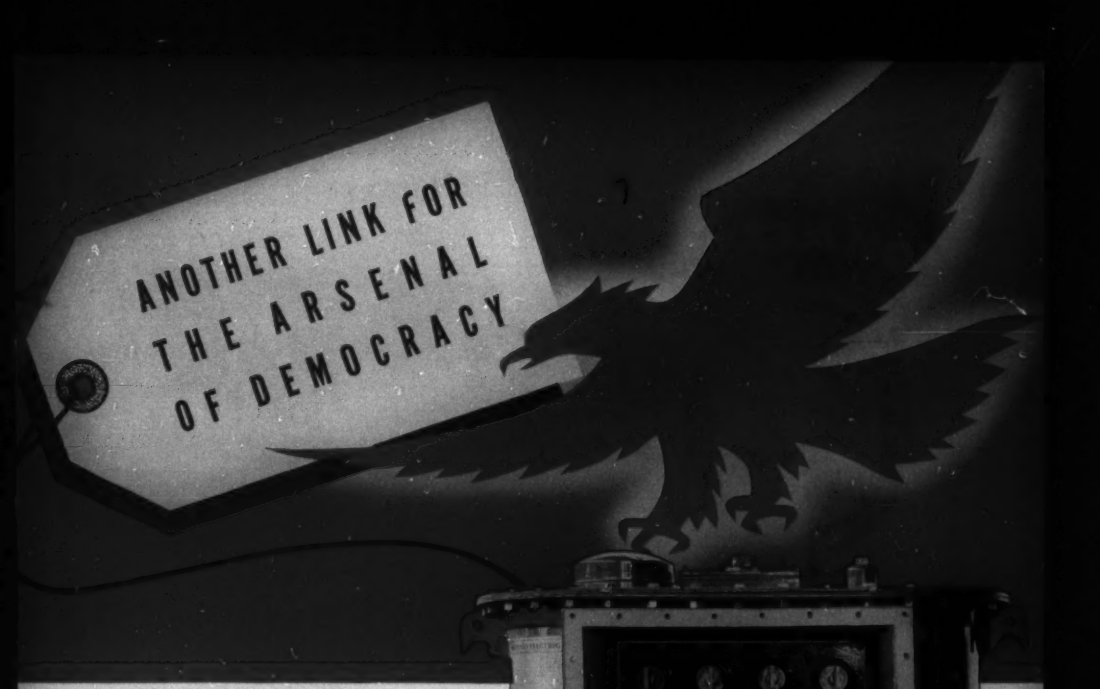
RHEOSTATS · RESISTORS · TAP SWITCHES

ADVERTISERS

	Page
Acme Electric & Mfg. Company, The	20
Allis-Chalmers Mfg. Company	*
Aluminum Company of America	23
American Bridge Company	*
American Lava Corporation	5
American Steel & Wire Company	*
American Tel. & Tel. Company	29
Armstrong Cork Company	*
Behr, Leo	20
Belden Manufacturing Company	*
Benwood Linze Co., The	24
Biddle Company, James G.	21
Black & Veatch	26
Burndy Engineering Company, Inc.	25
Carnegie-Illinois Steel Corporation	15
Chicago Transformer Corporation	*
Classified Advertisements	14
Columbia Electric Mfg. Company	22
Copperweld Steel Company	3
Corning Glass Works	*
Crescent Ins. Wire & Cable Co., Inc.	25
Dixon's Typhonite Eldorado Pencils	19
Doremus & Company	14
DuMont Laboratories, Inc., Allen B.	*
Electrical Engineering	*
Electrical Modernization Bureau	20
Engineering Directory	26
Engg. Societies Personnel Service, Inc.	26
Engg. Societies Library	*
Ferranti Electric, Inc.	2
Fowle & Company, Frank F.	26
General Cable Corporation	*
General Electric Company	8, 10
General Radio Company	17
Gibson Electric Company	*
Hazard Insulated Wire Works	4th Cover
International Resistance Company	*
International Telephone & Radio Mfg. Co.	9
I-T-E Circuit Breaker Company	*
Irvington Varnish & Insulator Co.	4
Jackson & Moreland	26
Kerite Ins. Wire & Cable Co., Inc.	13
Kuhlman Electric Company	3rd Cover
Lapp Insulator Company, Inc.	7
Leeds & Northrup Company	12
Marine Rules	24
Mineralac Electric Company	24
Minnesota Mining & Mfg. Company	*
National Carbon Company, Inc.	*
National Electric Products Corporation	16
New Products	16, 18
Norma-Hoffmann Bearings Corporation	1
Ohio Brass Company	2nd Cover
Ohmite Manufacturing Company	30
Okonite Company, The	4th Cover
Polachek, Z. H.	26
Roebling's Sons Company, John A.	*
Roller-Smith Company	24
Rowan Controller Company, The	22
Sanderson & Porter	26
Sargent & Lundy	26
Science Abstracts	22
Sola Electric Company	*
Solar Manufacturing Corporation	18
Standards of AIEE	6, 21, 24
Taylor & Company, A. Y.	26
Trade Literature	14
Union Carbide & Carbon Corp.	*
United States Steel Corp. Subsidiary	15
United Transformer Corporation	22
Universal Clay Products Company, The	24
Warren, Howard S.	26
Westinghouse Electric & Mfg. Co.	27
Weston Electrical Instrument Corp.	11
White Engineering Corp., The J. G.	26
Wopat, J. W.	26
Wray & Company, J. G.	26

* *See previous issues.*



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Because they are filled with a non-explosive, non-inflammable, inert cooling fluid they are 100% safe.

Kuhlman SAF-T-KUHL Transformers may be installed at the load center—even on beams up near the ceiling—thus saving floor space. (2) eliminating expensive vaults. (3) improving voltage regulation and (4) avoiding much of the expense of secondary copper. Write today for further facts about Kuhlman SAF-T-KUHL Transformers.

Kuhlman

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TYPE R

Meets all "code" requirements but is limited to 50° C. operation.

PERFORMANCE
TYPE RP

This better grade insulation permits operation at 60° C. Carries heavier current loadings or allows use of smaller size conductors.

HAZARD PERFORMITE
TYPE RH

A superior insulation in every respect. Operating temperature 75° C. Permits still greater current loadings or even smaller conductors. Performite is super-aging... resistant to heat and moisture... lasts indefinitely... meets Federal Specs. J-C-106-a and J-C-121.

SECOND... Compare Typical Wiring Costs of All Three!

Conductor Size A W G	Carrying Capacity in Amperes 3 Cond. 30 Ambient			Relative Cost* per 100 Amp. — ft. (IAEI Bulletin, Jan. 1941)		
	Type R	Type RP	HAZARD Performite Type RH	Type R	Type RP	HAZARD Performite Type RH
2	80	96	115	$.867	.770	.670
4/0	160	193	230	$.970	.870	.740

*Naturally if the full carrying capacity of the conductors is not available because of excessive voltage drop, the comparison will have to be modified proportionately.

WITH ALL ITS ADVANTAGES... HAZARD PERFORMITE COSTS LESS PER AMPERE CARRIED

There are the facts! Relative costs figured from actual installations show that even the first cost of HAZARD Performite is actually less than Type R wire in a great many cases. This is true because this superior insulation permits greater load carrying or makes it possible to use smaller conductors for the same load. Both ways bring important copper savings and add materially to the life of the circuit.

For full information on HAZARD Performite, Type RH or Type RHT (small diameter for new wiring and rewiring), WRITE TODAY.

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PERFORMITE TYPE RH